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AIR VEHICLE TECHNOLOGY INTEGRATION PROGRAM (AVTIP)

Delivery Order 0054: Opportune Landing Site (OLS) Critical Experiment

Capt. Justin R. Rufa, Kenneth Eizenga, Carol Ventresca, and Robert McCarty

Control Systems Development and Applications Branch
Control Sciences Division

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14. ABSTRACT
The Opportune Landing Site (OLS) Software Demonstration Program heralds an intriguing and exciting concept in the potential capability for United States military forces acting throughout the globe. The OLS software components were designed by Boeing and by the US Army's Engineer Research and Development Center (ERDC) Cold Regions Research and Engineering Laboratory (CRREL) working within a cooperative agreement to develop software that would find landing sites that were flat and free of vegetation, standing water, obstructions, and with sufficient strength to support aircraft operations. The OLS-MS software was demonstrated in St. Clair County, Illinois. AMC tasked a trained STT member to identify all suitable landing areas in Eastern St. Clair County to compare with the software results. All 25 sites identified by the OLS software and inspected by the reviewers were determined to be suitable. Of the 16 sites found using traditional methods, 18.75% (3 out of 16) of those identified manually were found to be unacceptable upon inspection. The OLS Demonstration proved the concept that software can assess landing-site geometry and can estimate candidate OLS bearing strength.

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Executive Summary

The Opportune Landing Site (OLS) Software Demonstration Program heralds an intriguing and exciting concept in the potential capability for United States military forces acting throughout the globe. US Defense Planning Guidance requires that military forces be highly mobile and capable of rapid global response to affect a wide range of military options. This requirement creates an increasing dependence on air mobility for rapid deployment and effective, efficient sustainment. This concept of an expeditionary-style military requires that military operations take place without reliance on indigenous infrastructure. However, in order to operate anywhere anytime, US military forces must be able to take off and land their aircraft using natural terrain, rather than developed airfields. At present, this capability is provided by Special Tactics Teams (STTs) who must visit a proposed location and assess the site for landing suitability. A site survey provides an accurate assessment of the terrain, the soil strength, and the necessary space. However, the assessment is a time-consuming process, and sending a team into potentially hostile territory risks detection, thereby compromising their safety or success of the mission. Further, the STT may not be able to accomplish assessment of the best possible sites in a timely manner.

The OLS software components were designed by Boeing and by the US Army's Engineer Research and Development Center (ERDC) Cold Regions Research and Engineering Laboratory (CRREL) working within a cooperative agreement to develop software that would find landing sites that were flat and free of vegetation, standing water, obstructions, and with sufficient strength to support aircraft operations. Boeing developed algorithms that would find such sites and determine soil type based upon Landsat imagery, while ERDC-CRREL developed a means to infer soil strength from models and a database of information about soils.

The purpose of this program was to demonstrate and verify the software capabilities, as well as to make modifications as needed and plot the way ahead for transition of an OLS system to the warfighter. Objectives of the program were to

1. Determine soil types for potential worldwide landing sites and perform data collections at surrogate locations.
2. Validate satellite-based soil typing algorithms.
3. Validate the soil strength algorithms that utilize soil type and moisture content.
4. Integrate the algorithms and demonstrate their effectiveness.

These objectives were achieved, except integration of the algorithms. The OLS code consists of three software modules. OLS-MS, the runway-finding module, uses image processing to identify candidate landing sites, highlighting areas with suitable geometry that are free of standing water, heavy vegetation, and obstacles. Another module, OLS-EVM, applies the Extended Vector Method to imagery to determine soil type and strata. The Fast All-Season Soil Strength (FASST) model uses weather data and soil type to determine soil moisture profile and, in turn, an estimate of soil strength.

Five groups of activities took place in executing the OLS Demonstration Program. A Military Utility Analysis was conducted. A systems engineering approach was applied to determine requirements and evaluate alternatives with regard to those requirements. The third and fourth sets of activities involved testing and evaluating the software and enhancing the existing algorithms, including developing and improving soil type identification algorithms. The program ended with an overall demonstration of the OLS software capabilities.

The OLS-MS software was demonstrated in St. Clair County, Illinois. AMC tasked a trained STT member to identify all suitable landing areas in Eastern St. Clair County to compare

with the software results. All 25 sites identified by the OLS software and inspected by the reviewers were determined to be suitable. Of the 16 sites found using traditional methods, 18.75% (3 out of 16) of those identified manually were found to be unacceptable upon inspection. The OLS-EVM and FAAST software were demonstrated at Vandenberg Air Force Base (AFB) and Holloman AFB. The OLS-EVM software performed flawlessly at Vandenberg but at Holloman determined an incorrect soil type. However, that information passed through the FASST software still produced acceptable strength determination because the actual soil type had similar characteristics to those of the inferred soil type. The OLS software performed well in identifying potentially suitable landing zones. This demonstration also highlighted areas for improvement, such as better algorithms for identifying soil strength and integration among the software modules.

The OLS Demonstration proved the concept that software can assess landing-site geometry and can estimate candidate OLS bearing strength. The program also delivered software, documentation of software performance, and a Technology Maturation Plan to point the way forward for OLS system enhancement. This includes a well conceived list of the actions required to prepare an OLS system for transition to the warfighter.

Additionally, the program pointed out the value of pulling together a cooperative team that utilized the strengths of the Air Force Research Laboratory (AFRL), industry, and the Army's ERDC. Each part of the team brought exceptional talent and capability to bear upon the problem, and their combined efforts resulted in a hugely successful demonstration.

Although more work needs to be done to obviate the need for the STTs' hands-on assessments of OLSs, the path to that result is clearly defined, awaiting only the time and funding to complete the job of making this capability a reality.

1. Introduction and Objectives

1.1. The Need for an Opportune Landing System

The United States (US) Defense Planning Guidance requires US military forces to be highly mobile and capable of rapid global response to affect a wide range of military options. As US forces become more expeditionary in nature, there is an increasing dependence on air mobility and the Mobility Air Forces (MAF) for rapid deployment and effective, efficient sustainment. Inherent in this expeditionary concept is the requirement to be able to conduct military operations with minimal or no reliance upon indigenous infrastructure. To provide this capability, US forces must be able to accurately determine the suitability of a proposed site. Today this determination relies almost exclusively upon a STT visiting the location and assessing the proposed site or landing zone. While a site survey provides an accurate assessment, it is a time-consuming process and one that can compromise future operations if the presence of a STT is detected.

An Opportune Landing System that would enable remote surveys of large areas for possible landing sites and drop zones would reduce the threat exposure, shorten the mission-planning cycle, result in the need for fewer site visits by STTs, and reduce the pre-mission manpower required for austere-area operations. For these reasons, the OLS Demonstration Program was performed.

1.2. OLS Program Objectives

The overall goal of the OLS software is to identify natural terrain landing sites that are long enough, wide enough, flat enough, vegetation free, standing water free, and obstacle free with sufficient soil strength to support aircraft operations. The specific program objectives in supporting this overall capability were as follows:

1. Determine soil types for potential worldwide landing sites and perform data collections at surrogate locations.
2. Validate satellite-based soil typing algorithms.
3. Validate the soil strength algorithms that utilize soil type and moisture content.
4. Integrate the algorithms and demonstrate.

The program achieved all objectives except the integration of algorithms under Objective #4. In addition to these achievements, the program management/systems engineering team also produced a technology maturation plan to document activities recommended to reduce risk to acceptable levels for future system development efforts. Some of the other documentation, in particular from ERDC-CRREL, enumerated more detailed objectives and tasks. The program objectives listed here are the summary objectives for the entire effort.

1.3. Organization of this Report

This report discusses the Opportune Landing Site (OLS) Software Demonstration Program in five sections. Section 1 discusses the need for an OLS System and the overall objectives of the current program. Section 2 details the background and history of the program and the software foundations upon which it was built. Section 3 describes the approach taken to develop and test the OLS software. Section 4 describes results of the effort, while Sections 5 completes the report with conclusions reached throughout the program and recommendations for ways to continue developing the OLS technology in the future. Appendix A contains an

annotated bibliography that can be used to find more information on a variety of OLS issues related to the system demonstration.

2. Background

2.1. The Need

2.1.1. Military Requirement Background

Operations of the future are expected to occur in areas remote from the traditional military infrastructure. The Mobility Air Forces (MAF) will need to deliver personnel, cargo, equipment, and humanitarian aid to remote locations worldwide without being tied to traditional fixed base support located in either the Continental United States (CONUS) or outside the CONUS (OCONUS).

An effective OLS system would enable the anywhere aspect of the Air Mobility goal for an anywhere, anytime operational capability. It would enable the Global aspect of the Air Force Vision of “Global Vigilance, Reach, and Power”. Such a system would enhance the mission and threat-avoidance capability of a future mobility aircraft. The ability to perform “hands-off” analysis of potential Landing Zones (LZs) worldwide would produce more opportunities to land close to the desired area of operations and give a higher level of assurance that the selected landing site would be suitable for these operations.

Additional landing sites could be identified largely because designating an appropriate OLS would not be dependent upon the ability of or the time required for a Special Tactics Team (STT) to physically survey the site as is now required. Threat avoidance would be achieved by obviating the need for the mission marker, in the form of an STT presence at the intended operations site; so the threat avoided would be twofold—that to the STT and that to the aircraft intended to land and its associated operations. Higher assurance of landing suitability would result in safer landings and reduced maintenance costs associated with an intended area of operations

2.1.2. Concept of Employment of an OLS System

Table 1 illustrates the concept of employment of an OLS system as a mission-planning tool. Days, weeks, and perhaps even months prior to the deployment of a mission, imagery of a region in which operations are possible could be processed at leisure to identify candidate LZs. In the days leading up to a mission, when the geographical area is narrowed, the preprocessed results could be updated with more recent imagery, weather data, and possibly higher resolution images to identify potential LZs.

The OLS system is a decision aid for the automated selection of potential landing sites. It determines the area and soil suitability for landing zones, drop zones, and assesses trafficability to permit airfield-independent, austere operations. As currently programmed, the runway-finder module specifies an orientation for each candidate runway. However, the software is capable of indicating areas suitable for landing or ground operations, marshalling areas, drop zones, etc. and could satisfy this need as well. Employment of an effective OLS system would reduce mission planning time from days to hours through faster processing of the geographical data concerning the areas of interest and obviating the need to have STTs physically travel to and survey the sites. Also, the higher accuracy rate of the software compared to human inspection techniques in determining site suitability would reduce the total number of sites that need to be surveyed. This will be true even if the near-term concept of employment is that an STT will continue to be sent out prior to committing a high-value asset, such as a mobility aircraft, to a particular OLS.

One concept of employment is that the user would identify a requirement to land within a region and then forward a request to the entity that owns the OLS system. The request would

include the geographical region or a specific location and certain constraints such as size, type of operation, etc. The OLS system would analyze available data and provide the user with initial candidate areas. The requester would then refine the mission plan and request newer information or refinement of the previously provided information. The OLS system would return a slate of potential LZs and retain those results for future use. The OLS system would operate within the standard Air Mobility Command (AMC) information architecture and would be capable of exporting the data to other applications as appropriate for mission decision support.

Because mission planning is an ongoing process, the authors of this report envision the use of the system as a spiral rather than a linear process. Imagery in regions of potential interest could be processed periodically so that information is never more than one month (six weeks, three months, as determined by the ultimate owner of the OLS system) old, with updates being accomplished rapidly once the MAF focuses on a particular area for potential missions.

The current process of identifying natural terrain or opportune landing sites is a manually intensive process as seen in Table 1 under “Current Method”. The right column shows how use of OLS software can shorten the process and reduce the number of times that the STT would need to inspect potential landing sites. As AMC assumes responsibility for the base opening mission, the Command becomes more interested in tools to support this manually intensive process.

Table 1. Current vs. OLS Enhanced Process for Determining Natural Terrain Landing Sites

Current Method	OLS Enhanced Method @ FOC
AMC identifies the need to conduct operations from a non-paved surface	AMC identifies the need to conduct operations from a non-paved surface
STT makes an initial cut	OLS System Finds Sites
AMC Redefines Operation	AMC Evaluates Results
STT Input	
AMC task for site survey	
STT Does Survey	STT Does Survey
STT Reports Results	STT Reports Results
AMC Evaluates Results	AMC Evaluates Results
AMC Tasks Mission	AMC Tasks Mission
AMC Tasks STT for Operation	AMC Tasks STT for Operation
STT Deploys for Operation	STT Deploys for Operation

2.2. History Prior to Current Program

The OLS program began in 1996 within The Boeing Company as a supporting Internal Research and Development (IRAD) effort to the Advanced Theater Transport (ATT) program. The US Army had a stated need for a Super-Short Takeoff and Landing (SSTOL) air vehicle to deliver 40,000 pounds to natural terrain landing sites that were 750 feet or less in length (TRADOC Pamphlet 525-66). AMC also became interested in OLS-type technology in 2004 when the Command began the push for operations in austere areas (Almassy et al. 2007, 1–2, Appendix A.1.1).

The OLS program was initiated to provide a means to assess the suitability of natural terrain landing sites through the use of Boeing’s previously developed remote sensing software technology. While a site survey provides an accurate assessment, it is a time-consuming process,

inherently dangerous, and one that can compromise future operations if the presence of a STT is detected. Further detail can be found in Boeing's Final Report (Almassy et al. 2007, 1–2, A.1.1).

The Army's Engineer Research and Development Center (ERDC) played a key role in the formation and initiation of the OLS effort. Through the ERDC Geophysics and Structures Lab, ERDC's Cold Regions Research and Engineering Lab (CRREL) learned of a development tool by Boeing to locate opportune landing sites. ERDC-CRREL followed up with Boeing and Bowling Green State University, which activities led to a meeting in July of 2001. In November the following year Boeing asked ERDC to meet in Dayton, OH, where they wrote a joint proposal that Boeing submitted to the DoD. The proposal essentially became the current OLS program, with one exception. The proposal suggested using hyperspectral signatures for soil type, but multispectral was eventually used. The work was not funded but was resubmitted for the US Transportation Command's (USTRANSCOM's) Transformation Technology Initiative (TTI). The project was chosen for funding by USTRANSCOM, to be directed by AMC and executed by the Air Vehicles Directorate of the Air Force Research Laboratory (AFRL) (Ryerson, Shoop, and Koenig, 2007, 5, A.1.2).

2.3. Software Foundations

2.3.3. Boeing/ERDC Development Background

Information for this section is taken from the Boeing final report (citation at end of section). Boeing contracted with BG Image, Bowling Green, Ohio, to develop a method for using satellite and aerial photography to select natural terrain landing zones that were flat, free of standing water, and clear of obstructions and heavy vegetation. Dr. Robert K. Vincent, principal scientist for BG Image, developed algorithms that, when applied to Landsat satellite imagery, found such places. Throughout 1997 and 1998, Dr. Vincent, along with some of his graduate students at Bowling Green State University and Boeing personnel, visited US field locations of varying topography and climatology. He postulated that the acceptable threshold for flatness and vegetation was a function of annual rainfall for any given location. However, in 1999 Boeing stopped funding the OLS research and his postulated ideas were never verified.

In 2002, Boeing was approached by personnel from the ERDC-CRREL about the possibility of continuing the development of the OLS algorithms as a joint effort that would enable ERDC-CRREL to further develop the OLS algorithms to determine soil type. Boeing and ERDC agreed to proceed with a Cooperative Research and Development Agreement to continue developing OLS technology in November 2002, but little progress was made due to lack of funding. In 2003, Boeing developed a stand-alone C++ driven, Graphic User Interface (GUI) for the original Vincent-developed algorithms. This GUI processed individual Landsat images [either Landsat 5 Thematic Mapper ™ or Landsat 7 Thematic Mapper Plus (TM+)]. However, the algorithms analyzed only flat, obstacle free, standing water free, heavy vegetation free areas, and did not address soil strength.

In April 2003, Boeing and ERDC-CRREL submitted a white paper at AFRL's request describing the OLS concept and a program to develop and demonstrate the capability. AFRL passed the white paper to the USTRANSCOM.

The original Boeing/ERDC-CRREL proposal was submitted in April 2004 to AFRL. It proposed using the Vincent-developed BLSI "flatness algorithms" to locate suitable natural terrain landing sites and ERDC-CRREL-developed terrain Fast All-Season Soil State (FASST) model to compute soil bearing strength. Boeing was to develop algorithms that determined soil grain size, organic material content, and mineral content by analyzing hyperspectral satellite imagery (Hyperion). From grain size, organic material, and mineral content, ERDC-CRREL was

to determine soil type, which was an input to the FASST model (Almassy et al. 2007, 6–8, A.1.1).

2.3.4. Inference Regarding Soil Strength (FASST-Related Technology)

Information for this section was taken from the CRREL final report (citation at the end of the section). Soil strength is primarily a function of soil type and moisture. At present, it is not possible to extract sufficient soil moisture information from current satellite sensors to determine the soil strength. Therefore, either in situ measurements or state-of-the-ground models are required to obtain the soil moisture information needed to predict soil strength. In remote locations not controlled by friendly forces, it is highly unlikely that in situ measurements will be available. Therefore, physics-based state-of-the-ground models that predict soil moisture profiles based on knowledge of the soil type and the meteorological boundary conditions are the logical solution. Meteorological boundary conditions are readily available from mesoscale models [Mesoscale Model 5 (MM5) or Weather Research and Forecasting (WRF)] run operationally by the Air Force Weather Agency (AFWA). Soil type is inferred from satellite data using the Boeing Opportune Landing Site-Extended Vector Method (OLS-EVM) application, while the soil moisture is predicted from knowledge of the soil type using the physics-based 1-D Fast All-Season Soil Strength (FASST) model. Soil strength, in terms of the California Bearing Ratio (CBR), is determined from the soil type and the soil moisture profile (Ryerson, Shoop, and Koenig, OLS Final Report, p 15, 2008). ERDC already had developed the FASST software to predict soil moisture, but acknowledged the CBR algorithms needed improvement. The missing element for bringing the two pieces of software together remained soil type identification. (Ryerson, Shoop, and Koenig 2007, A.1.2).

2.4. Team Formation and Structure

When funding became available through the USTRANSCOM TTI, AMC agreed to manage the OLS Demonstration Program. AMC contacted AFRL, which agreed to execute the program. The Control Systems Development and Applications Branch of the Control Sciences Division of the Air Vehicles Directorate (RBCC, formerly VACC) of AFRL was selected.

The Boeing Company was selected to enhance and integrate the software it had developed for this purpose. Boeing teamed with BG Image of Bowling Green, Ohio, as a collaborator in image analysis enhancement. Boeing and BG Image performed a military utility study and continued work on algorithms for assessment of soil firmness and refinement of the software. Because of its expertise in soil analyses, ERDC-CRREL was selected as a partner to be an objective third party to develop the “ground truth” against which the software performance would be validated. In addition, ERDC-CRREL’s expertise in modeling soil strength was employed in the development of parts of the software suite.

Agreements between AFRL, Boeing, and ERDC-CRREL were finalized in July 2004. In August, SynGenics Corporation was brought in to implement a systems engineering approach to the execution of the OLS Demonstration Program. A kickoff meeting was held in September 2004.

AMC managed the effort and provided customer input. AFSOC was involved in some of the requirements-generation activities. Input from AFSOC personnel trained in performing LZ site surveys was invaluable in guiding the documentation of requirements and structuring software performance. Part of the ERDC-CRREL role was to perform a sensitivity analysis of sorts, aiding in the refinement of thresholds and improved understanding of the data available. This evaluation and feedback process with Boeing enabled an empirical approach to setting thresholds for screening candidate OLSs. The diverse team had the right combination of skill sets to effectively perform the program.

3. Approach

There were five major groups of activities in the execution of the OLS Demonstration Program. The first was a Military Utility Analysis. The second was a systems engineering approach to requirements. These helped to define the third and fourth sets of activities which were test and evaluation of the software and improving the existing algorithms. Improving the existing algorithms also involved developing soil type identification algorithms and software. Finally, the program ended with an overall demonstration of the capability. Both Boeing and ERDC-CRREL documented a chronological description of their participation in the OLS demonstration program in their respective final reports (A.1.1 and A.1.2). AFRL had planned to use some hyperspectral data from another AFRL program for identifying soil type. Unfortunately the hyperspectral sensor was never flown and alternative methods for determining soil type were needed. These details can be found in Appendix B, Program Development.

3.1. Military Utility Analysis

The first task of the AFRL-contracted program was to determine the military utility of an OLS capability. This study was completed to provide AMC with a potential database of non-airfield austere operating locations throughout the world that could be used in future operations.

Due to the large amount of time and manpower needed to analyze the whole world for OLS sites, AMC suggested that Boeing limit the study area to areas of strategic interest to the United States, including Asian and Middle Eastern regions. Studying these areas would result in an added benefit if the study also identified the soil types in these countries.

AFRL provided Landsat imagery of the areas of interest; and Boeing developed a software module to count opportune landing sites per image. Since anti-access strategy can be defeated by simply increasing entry opportunities beyond that which an enemy can defend, military utility was deemed to be increased as the ratio between OLS-MS identified sites and fixed airfields increased (Almassy. et al. 2007, A.1.1).

3.2. Systems Engineering (SE) Approach

Systems Engineering Tailored For Science & Technology (SETFST) is a process, a systematic way of handling the often overwhelming details necessary to define requirements, and then to analyze and select alternatives in the face of competing or incomplete solutions to problems. Separating the *must-have* from the *nice-to-have* aspects of a future capability can be an important distinction and can help to clarify project objectives so that teams can make better decisions while creating, developing, or maturing a technology.

The OLS system must offer users the same level of fidelity, accuracy, repeatability, and capability[1] as manned STTs provide today. The OLS system must be compatible with, and use the current geospatial datum reference, World Geodetic System (WGS) 84, as well as the AMC method of expressing soil-bearing capacity (currently the CBR, but in the future this might be measured as the number of passes for a given aircraft type and weight). OLS system products must be in a format (electronic) that operators can manipulate, store, receive, or transmit securely.

[1] In terms of LZ site selection; i.e., suitability of the landing surface and sub-surface to support the required operations in addition to selecting adequate and appropriate arrival and departure corridors.

The potential for improvement exists in the current LZ site selection process. One opportunity for improvement is reduction of the cycle time required to conduct a site survey once the need is identified. Currently, an STT must be assembled and transported to the proposed LZ site; the team must collect the data, analyze it, and report the results. Another potential improvement stems from the current need for personnel to conduct site surveys. The mere fact that an area is being surveyed could easily forewarn adversaries of forthcoming operations, placing both the survey team and the mission at risk.

3.2.1. Requirements Establishment

The SETFST process enabled the OLS team to establish clear requirements within a complex problem space. The team was able to define, in a measurable way, what qualified as success for the OLS-MS software—how large, flat, homogenous, water-free, and vegetation-free did an area need to be; how well did the software need to identify collateral objects such as nearby utility poles and wires. Having clarity on the solution gave the software developers the ability to write to a measured degree of accuracy.

A portion of the kickoff meeting was devoted to instruction in the systems engineering decision analysis process to be applied to the program. The team then listed eight potential customers and brainstormed evaluation criteria for an OLS System to meet these customers' needs. Criteria were generated that fell into the following types: cost, integration, logistics, ownership, performance, schedule, and user perception. Criteria were developed for three timeframes—reflecting the end of the current concept demonstration, a milestone B-like decision, and a milestone C-like decision for an initial operating capability.

The OLS software uses remote imagery to scan for obstacle-free, water-free and heavy vegetation-free areas for evaluation as candidate LZs. It then uses a myriad of data sources to infer soil type, and it uses mesoscale atmospheric modeling and soil moisture modeling to infer soil strength. Areas that pass threshold values for openness; absence of heavy vegetation, standing water, and obstacles; smoothness; and soil strength are identified as opportune landing sites.

3.2.2. Evaluation against Requirements

The OLS team conducted a systems engineering analysis for program demonstration requirements at the end of this concept exploration. Each alternative was evaluated against requirements for the demonstration. Eight criteria were evaluated, including three KPPs:

- KPP P01: Capability to identify suitable landing sites in a given area, given that suit-able landing sites exist. Suitable was defined as flat, obstacle free, standing water free, and heavy vegetation free, without considering bearing strength. Exit criterion: 50% found.
- KPP P02: Capability to determine bearing strength of identified landing sites. Measurement defined as predicted CBR/actual measured CBR. Exit criterion: 1.05 or less.
- KPP P04: Repeatability. Defined as percentage of time OLS software returns the same results using the same entry parameters while evaluating the same Landsat image. Exit criterion: 90%.

Five additional evaluation criteria were established with an eye toward OLS system maturation. While none of these were KPPs for the current program, each of the following was evaluated, but no level was defined as failure at this stage:

- P03: Low incidence of false positives—a measure of accuracy—the probability of designating an unsuitable landing site as suitable. The definition of suitable at this stage relates to geometry of the site and excludes bearing strength.
- P07: Flexibility and longevity—the ability of OLS software to function even if Landsat or other asset relied upon as a data source is no longer available.
- P09: Capability to operate in all weather conditions in which operations would be conducted, regardless of presence of cloud cover, precipitation, or other obscurants.
- P11: Ability to accept user-defined parameters—the ability of OLS software to process inputs provided by users, including parameters like length, width, ratio requirement, CBR, glideslope, etc.
- P12: Flexibility in finding more than LZs—ability of OLS software to perform other functions; e.g., assessing overland mobility, finding areas for base camps and drop zones, etc.

The objective of the OLS demonstration was to evaluate the software against the requirements, particularly the exit criteria, and to demonstrate to AMC that the KPPs for this program at the 29 November 2006 meeting were met.

The team also looked at an interim capability after accomplishment of the technology maturation required to reduce risk for system development and demonstration; and at a long-term capability for start of production and deployment, leading to initial operational capability. The demonstration requirements with thresholds, objectives, and comments are published in Appendix D of this report. Prior to completion of the SETFST process the CONOPs in Appendix C guided the program.

3.2.3. Demonstration Plan

A practical demonstration of the utility and accuracy of the application took place in May–July 2007, with final results briefed to AMC in September that year.

The Demonstration was intended to showcase the capabilities of the OLS software to the AMC staff, demonstrate the current state of the technology, and reveal the potential of the technology for further maturation, development, and deployment. Further objectives were to demonstrate how well KPPs and exit criteria for the OLS Demonstration Program had been met, and to lay the foundation for the technology maturation and risk-mitigation way forward.

The Boeing Company provided software for locating opportune landing sites and for identifying soil type using remote imagery. The US Army Corps of Engineers, (USACE) ERDC-CRREL evaluated Boeing software on the ground and provided soil moisture prediction tools and soil strength prediction algorithms.

The demonstrations not only proved the current level of software sophistication, but pointed out probable future needs for an OLS system as the future warfighter's missions becomes more expeditionary in nature. The OLS-MS demonstration highlighted the need for greater software control in being able to add adjacent roads and runways to areas selected. Currently, adjacent asphalt is rejected by the software as being inhomogeneous.

A continuing problem for the OLS-EVS module is identifying, from surface pictures, the quality of soil. It is as if the sensor creating the images being analyzed needs X-ray vision (since

STT's evaluate the soil to at least a 3 foot depth). Although certain algorithms are currently quite sophisticated, more is needed. The application of systems engineering processes to the OLS program was successful in identifying future directions, pointing out current weaknesses, and permitting the team to make realistic estimates of future development timeframes. It also focused the team's research efforts on identifying potential customers and users, which helps in specifying requirements to a sufficiently specific degree to be addressed appropriately.

3.3. Software Description and Development

3.3.4. Software Components

The OLS software comprises four discrete modules of computer-coded algorithms. One module, OLS-MS, uses satellite imagery to identify candidate landing areas. Another module, OLS-EVM, uses imagery and topographic data to determine soil type. A third module, FASST, uses weather data and soil type to determine soil moisture content. A fourth module within FASST uses soil type and moisture content to estimate soil strength.

3.3.5. OLS—Multispectral Approach (MS)

Information for this section came from the Boeing final report (citation at the end of the section). OLS-MS is the "flatness" module of the OLS package. The initial approach for OLS-MS was to analyze raw (unmanipulated) Landsat imagery to locate flat, water-free, obstacle-free, heavy vegetation-free pixels and to assemble suitable pixels into rectangles of user-specified size and orientation for runway. The algorithms themselves were to be coded in an appropriate computing language and the images processed with a Boeing-developed graphic user interface (GUI). Boeing had previously developed a C++ package and a Windows-based GUI. However, the Windows operating system was very poor at reading, manipulating, and processing Landsat imagery. After investigating several industry standard Geographic Information System software operating systems, Boeing chose to code the algorithms in Interface Definition Language (IDL) and to read, manipulate, and process the imagery using Environment for Visualizing Images (ENVI) software. This enabled Boeing to use industry standard toolsets to prepare the imagery for evaluation and to display results.

The flatness algorithms themselves are straightforward applications of physics. Pixels that are reflecting in the blue/green portion of the electromagnetic spectrum but absorbing in the thermal spectrum are assumed to be water and are masked out of the image. Pixels with strong reflectance signatures in the visible green and complete absorption in the red (near IR) spectrum are assumed to be heavy vegetation and are also masked out. Adjacent pixels with uniform reflectance in each band up to a given threshold are assumed to be flat, obstacle free areas. Groups of pixels which pass all three tests are grouped together and evaluated to see if they meet the user specified geometry (length and width). If they meet all criteria, they are identified as a suitable OLS (Almassy et al. 2007, A.1.1).

3.3.6. OLS—Extended Vector Method (EVM)

Information for this section came from the Boeing final report (citation at the end of the section). The missing piece to ensure the OLS software completely evaluated the natural terrain landing site was algorithms to determine soil type. OLS-EVM is the soil type module of the OLS package. The OLS-EVM development was an extension of studies that were published by Endre E. Dobos in 1998. Boeing started with Dobos's basic ideas and then modified them to fit the specific purpose for OLS. The basic idea of the OLS-EVM is to use digital imagery of multiple spectral bands covering the same ground during different seasons of the year. These multi-spectral seasonal images are combined with digital terrain elevation images (DTED). Then

various mathematical combinations of these images are used to generate approximately 100 images that are used to predict soil type. Each of these 100 (referred to as vector layers) provide different pieces of information that may be used in combination to identify certain soil types.

The DTED images come from NASA's Shuttle Radar Topography Mission (SRTM). From an elevation image, additional images are computed that show the ground slope or curve. Also, Potential Drainage Density (PDD) images are computed from the elevation image. Potential Drainage Density is a computation specifically developed by Endre Dobos and his collegues, and is, in a sense, a prediction of the amount of water that can drain into an area of ground.

The multispectral images are composites of individual spectral bands from the visible portion of the electromagnetic spectrum (red, green and blue color bands), combined with additional bands (infrared and thermal) that the human eye cannot see. From the multispectral images radiance, reflectance and thermal images are computed. Radiance is a measure of electromagnetic energy measured by the sensor. Reflectance is calibrated radiance. Different combinations of the reflectance images provide enhanced images that measure the types and amounts of groundcover such as vegetation, soil, and composition (organic and mineral content).

Although these 100 digital images do not actually "see" what is under the ground, information can be inferred, such as how the vegetation present changes from winter to summer, the minerals present in the topsoil, and how the water drains. This information can indicate what types of soil are exposed on the surface and down to a depth of approximately three feet. Another key piece of the EVM development is that all of these images are collected or computed for areas on the ground where the types of soil are already known. Then by performing certain mathematical computations on the images, the software can be "trained". Training the software is like telling the software, "This is what clay looks like, and this is what sand looks like". Once the software has a database (or spectral library) of known soil types, it can analyze digital imagery from a different location with unknown soils and identify them by comparing the imagery to the soils library stored in the database. Further detail can be found in Boeing's Final Report, (Almassy et al. 2007, A.1.1) and in Hines, C. Il and Wolboldt, M.W. 2008, A.6.11.

3.3.7. Fast All-Season Soil Strength (FASST)

Information for this section came from the CRREL report on FASST (citation at the end of the paragraph). The soil strength portion of the OLS software comes from the ERDC-CRREL-developed Fast All-Season Soil Strength (FASST) software. This 1-D dynamic state of the ground model was developed as part of the Army's Battlespace Terrain Reasoning and Awareness research program. It calculates the ground's moisture content, ice content, temperature, and freeze/thaw profiles, as well as soil strength and surface ice and snow accumulation/depletion. The fundamental operations of FASST are the calculation of an energy and water budget that quantifies both the flow of heat and moisture within the soil and also the exchange of heat and moisture at all interfaces (ground/air or ground/snow; snow/air) using both meteorological and terrain data. FASST is designed to accommodate a range of users, from those who have intricate knowledge of their site to those who know only the site location. It allows for 22 different terrain materials, including asphalt, concrete, bedrock, permanent snow, and the Unified Soil Classification System (USCS) soil types. At a minimum, the only weather information required is air temperature. (Frankenstein and Koenig, Fast All-Season Soil Strength (FASST). ERDC/CRREL SR-04-1, Abstract)

Further information on the FASST model can be found in reports A.4.1 and A.4.2 and conference paper A.6.12 referenced in Appendix A.

Within the OLS development period, work was done on enhancing the soil strength portion of the FASST software. ERDC-CRREL developed a soil strength database, conducted laboratory studies, and used the initial field testing to enhance their soil strength algorithms. This work is outlined in reports A.3.1 – A.3.7 and Conference Papers A.6.3. A.6.8-A.6.10, and A.6.13.

3.4. Initial Testing

3.4.8. ERDC Tasks

ERDC-CRREL was responsible for initial testing of the Boeing software. Based on the selected areas for the military utility analysis, ERDC-CRREL evaluated the software in Southern Indiana (two sites), El Centro Naval Air Facility, and Ft Bliss. The testing in these locations focused on getting detailed analysis of a single site at each location during the four major seasons of the year. In all cases, the software found areas that were long enough, wide enough, and flat enough. However, in most cases there was not sufficient soil strength at the location to support aircraft operations. At the point in time the sites were identified, the OLS-EVM software was not functional so that aspect of the criteria could only be evaluated in the final demonstration. Because the software was modified during the course of the program, none of the sites were identified by the final version of the software. Detailed information on the field testing conducted by ERDC-CRREL can be found in A.2.1-A.2.3 and conference papers A.6.6 and A.6.7.

ERDC-CRREL also examined an alternative approach to validating the Boeing software. It essentially involves checking the software results against a Geographic Information System (GIS) database of known features that would prevent a site from being suitable, such as standing water, power lines, roads, railroads etc. Geo-registration becomes an extremely important issue when this type of validation is pursued, and the team found many geo-registration issues as the program progressed. Unlike the field testing, this work was done with the final version of the software. Overall, depending on the area examined, ERDC-CRREL estimates that Boeing finds good sites approximately 75% of the time using this technique. Note however, that there are many potential sources of error besides the geo-registration of the data sources. The detailed results from this study can be found in (Ryerson, Dr. Charles C., Scott, Forrest R., and Tracy, Brian T., A.5.1) and conference paper (Ryerson, C.C., et al., A.6.14).

3.5. Final Demonstration Plan

The demonstration plan consisted of three separate tasks to show the effectiveness of the OLS software. Tests of repeatability, the capability to identify landing sites, and the capability to predict bearing strength were conducted to prove that the software met its KPPs. Further detail can be found in Boeing's and ERDC-CRREL's Final Report as well as the report on the field testing in St Clair County IL, (Almassy et al., 2007, A.1.1), (Ryerson, et al. 2007, A.1.2), (Ventresca et al, 2008, A.2.4).

4. Results

4.1. Military Utility Results

Details on the results of the military utility study can be found in Boeing's OLS Final Report Annotated Bibliography Reference A.1.1. Multiple counting methods were used for determining the number of various size OLS's that could be found in each region.

4.2. Final OLS Software Configuration

The current OLS package is a software application intended to be used as a military mission planning tool. The application is currently in a developmental state consisting of four discreet modules of computer coded algorithms. One module, OLS-MS, uses satellite imagery to identify candidate landing areas. Another module, OLS-EVM, uses imagery and topographic data to determine soil type. A third module, FASST, uses weather data and soil type to determine soil moisture content. A fourth module, CBR, uses soil type and moisture content to estimate soil strength. A companion OLS report, OLS Technology Maturation Plan, is a compilation of the tasks required to mature the modules from their current development state to a stand-alone software application. Further detail can be found in Boeing's and ERDC-CRREL's Final Reports, Annotated Bibliography Reference A.1.1 and A.2.2.

4.3. Demonstration Results

4.3.1. Demonstration of Capability to Identify Landing Sites

Boeing demonstrated OLS-MS's capability to identify landing sites on 5 June 2007 in Saint Clair County, Illinois. They ran the OLS "flatness" software on the April 07 Landsat image of the area to locate suitable landing areas dimensioned 1000 feet by 90 feet. The nominal 3500 feet was not used due to the software not reporting any sites this long.

To help verify Boeing's work, AMC tasked a former STT member to identify all suitable landing areas dimensioned 3,500 feet by 90 feet in the same area. The former STT member used aerial photography from Falcon View for the same area as the Landsat imagery used by Boeing. Falcon View does not provide the date the imagery was taken; however, the former STT member noticed that Mid-America Airport was still under construction in some of the imagery and it was opened in May of 1998. He completed this analysis on 23 May 2007.

On 5 June 2007, representatives from AFRL, AMC, ERDC-CRREL, SynGenics, GDAIS, and Boeing drove to several of the sites identified by the former STT member and OLS-MS to determine if these sites met the OLS requirements. The team inspected 25 of 40 sites identified by the OLS-MS software and 16 of 17 sites identified by the former STT member visually from surrounding roads since all sites were located on private land. All 25 sites found by Boeing were considered acceptable. These results compared favorably with the requirement of finding usable sites 50% of the time.

The manual method produced 17 candidate OLSs while the software survey of the same area indicated 40 possible sites. The team visited 39 sites in all, including 16 of the 17 found by the manual method and 25 of the 40 from the software analysis. Eight of these candidate OLSs were identified by both the manual method and the software; all were good sites. Of the 16 manually determined sites surveyed, 3 (18.75%) were found unsuitable. Two of the three were located on a relatively new construction site, thus the old imagery may have been a factor. Even so, one of the two sites near the construction also crossed a small drainage ditch and was

hampered by nearby telephone poles. The third unsuitable site appeared to cross some high tension power lines, but was difficult to get a good look at due to lack of nearby access roads.

None of these three sites was selected as a candidate site by the software. Of the 25 sites identified by the software and visited by the team, all were found to be acceptable, and some were found to be outstanding—better than those found by the STT-trained assessor. Two of the acceptable sites found by the officer were ruled out by the software because of winter-wheat vegetation that was present on the satellite image which was not present on the aerial photographs used for manual site selection. Further information of this testing is documented in the SynGenics report of the St Clair testing A.2.4.

Software performance was outstanding with respect to KPP P01, the capability to identify suitable OLSs in a given area. It also demonstrated a low incidence of false positives (0%), P03, which was not a KPP for this program but will be for a more mature OLS system.

4.3.2. Demonstration of Capability to Determine Bearing Strength

Two locations were selected for the evaluation of the capability to determine bearing strength. An Air Force Civil Engineer Support Agency (AFCESA) Airfield Pavement Evaluation (APE) team measured soil strength, soil moisture, soil density, and soil type to a depth of three feet at the demonstration locations; and forwarded the results to AFRL and to AMC. Soil strength was expressed using CBR as the unit of measure. Boeing executed the OLS-EVM software and provided the results of inferred soil type to AMC and AFRL. ERDC executed the FASST model for all 26 Unified Soil Classification System (USCS) soil types, using weather data obtained independently to predict soil moisture and bearing strength. ERDC provided results to AMC. AMC/A3RP compared the results and completed the assessment with respect to capability of the OLS-EVM software to determine bearing strength (P02). The OLS software was permitted to over-predict bearing strength by no more than 5% to meet this exit criterion and KPP. Predicting softer-than-actual CBR values was acceptable for the demo.

Soil strength is a function of soil type and soil moisture content. Therefore, accurate inference of soil strength is a function of the correct inference of USCS soil type, the accurate prediction of soil moisture content, valid assumptions of soil density and hydraulic properties, and the accuracy of the soil-strength algorithms. In addition, the prediction of soil moisture depends on soil type and meteorological conditions prior to the soil moisture prediction. Errors in any of these parameters will cause error in soil strength prediction. If the software did not successfully predict the CBR, it would be critical to acquire sufficient data to understand why and to achieve technology maturation for OLS system development.

The OLS Demonstration Plan, discussed in late November 2006 at AMC, suggested that a blind test of OLS soil-strength capability would best be conducted at Air Force bases because of the difficulty of accessing private land for field work. The following tasks conducted at the demo sites would allow full assessment of the requirements of KPP P02.

In February 2007, ERDC contacted the AFCESA APE team to determine their capabilities and to identify Air Force bases where required soil type, soil moisture, and soil strength measurements could be made by teams. After Boeing ran the OLS-MS software for each of these locations, the team concluded that Vandenberg AFB and Holloman AFB both possessed acceptable OLS sites.

Boeing was tasked with running its OLS-EVM software to determine the USCS soil types at the two locations, while ERDC-CRREL collected Air Force Weather Agency Weather data to feed into their FASST model for soil hardness predictions.

The AFCESA APE team completed their digs at each of the locations in the late July through early August 2007 timeframe. To verify Boeing and ERDC-CRREL's algorithms, AFCESA took CBR, soil moisture, soil density, and soil type measurements in a 100′ x 100′ square at the location given by the OLS-MS software. Further detail can be found in ERDC-ERDC-CRREL's Final Report, Annotated Bibliography Reference A.1.2.

The OLS software correctly identified Sand Silt Strata from the surface to 36 inches in depth at Vandenberg AFB. At Holloman, the software identified the soil type as Low Plasticity Clay, when AFCESA found Silt. Even though the soil type was misidentified, the resulting strength prediction turned out to be very good since the two soil types have similar strength properties. Determining soil strength is a very difficult problem. One of the key issues is the variability of measured data. Figure 1 shows measured CBR along with predicted CBR from the OLS software (both with the correct and incorrect soil type for Holloman). The black dots represent the measured data from AFCESA, and the large dispersion of data is readily seen. The soil moisture tended to be less than what was predicted by the software, however using the software produced an acceptable CBR prediction (see Table 2).

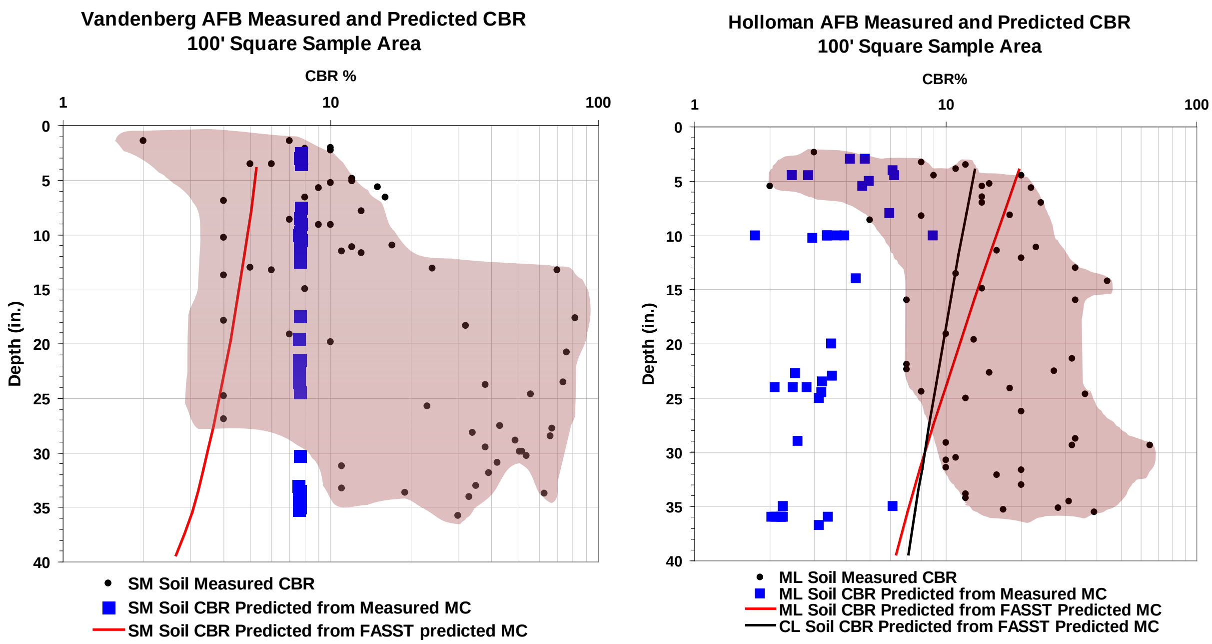

Figure 1. OLS Final Demo Measured and Predicted CBR

Table 2 contains the overall summary of the final demonstration results. The table shows that the overall goal of predicting the soil strength met the KPPs outlined in the requirements process by not overpredicting the soil strength.

Table 2. Summary of OLS-EVM Demonstration Results

		Soil Type	CBR Range	15th percentile CBR
Vandenberg	Software Predicted	SM – Silty Sand	3-5	
	AFCESA Measured	SM – Silty Sand	2-82	4-11
Holloman	Software Predicted	CL – Low Plasticity Clay	7-13	
	AFCESA Measured	ML - Silt	2-65	7-11

4.3.3. Demonstration of Repeatability

The software was tested for repeatability to show that it would output the same results independent of the computer and operator as long as the same version of OLS-MS was used. To conduct this test, AFRL employees ran the software ten times on a GeoTiff Landsat image and ten times on a *.fst Landsat image. Repeatability could only be assumed if each run gave the same number of OLS sites for the given input parameters, which indeed were the results of the testing.

4.3.4. Satisfaction of other criteria (P07, P09, P11, P12)

The other criteria used to evaluate the software are less data driven. In terms of Flexibility and Longevity (P07), AFRL rates the software as a 4 - marginally satisfactory. In theory the OLS-MS and EVM code can operate using any pixilated data source. However, no testing was accomplished to confirm this fact. In terms of Capability to Operate in All Weather (P09), AFRL rates the software as a 2 - unsatisfactory. This is due to the fact that the Landsat imagery the software uses cannot penetrate weather, combined with the fact that the operator would like to use the most current data possible to ensure that the situation on the ground has not changed. However, the use of the FASST tool within the OLS software does allow for the data to be updated, based on weather information in terms of its effect on soil strength. In terms of the Ability to Accept User-Defined Parameters (P11), AFRL rates the software as a 6 - very satisfactory. The rationale is that the user can define the runway size (based on pixel size) and orientation in the search for candidate natural terrain landing sites. In terms of Flexibility in Finding More than LZs (P12), AFRL rates the software as a 2 which corresponds to being able to identify LZ's and drop zones. The input criteria allows for the size of the runway to be adjusted such that it also identifies a drop zone.

5. Conclusions and Recommendations

5.1. Conclusions

Working together, AFRL, AMC, Boeing, and ERDC-CRREL were able to pool their resources and information using a SynGenics led systems engineering process to develop a basic system of software modules to find suitable landing sites using just satellite imagery analysis and weather data.

5.1.1. KPPs and Objectives

The demonstration KPPs were all met. The KPPs were:

- KPP P01: Capability to identify suitable landing sites in a given area, given that suitable landing sites exist. Suitable was defined as flat, obstacle free, standing water free, and heavy vegetation free, without considering bearing strength. Exit criterion: 50% found.
- KPP P02: Capability to determine bearing strength of identified landing sites. Measurement defined as predicted CBR/actual measured CBR. Exit criterion: 1.05 or less.
- KPP P04: Repeatability. Defined as percentage of time OLS software returns the same results using the same entry parameters while evaluating the same Landsat image. Exit criterion: 90%.

Three of the four objectives were completely met, leaving only integration of the software to be accomplished.

1. Determine soil types for potential worldwide landing sites and perform data collections at surrogate locations.
2. Validate satellite-based soil typing algorithms.
3. Validate the soil strength algorithms that utilize soil type and moisture content.
4. Integrate the algorithms and demonstrate.

5.1.2. Software Proof of Concept

In field testing on 5 Jun 07 in St. Clair County, Illinois, the OLS-MS software performed flawlessly. All 25 of the sites identified by the software and visited were considered suitable, while 3 of the 16 sites identified using traditional methods were deemed unsuitable. (It should be noted that at least one of those false positives was due to old imagery data.) These results greatly exceeded expectations as reflected in the KPPs.

The soil strength portion of the demonstration was also very successful. In late July through early August 2007 at Vandenberg and Holloman AFBs, an AFCESA team evaluated a site at each location that was picked using the OLS-MS software. FASST was able to determine moisture content (within reason) and the OLS-EVM software proved that it could determine soil type. In the case of Holloman the soil type was not correct; however, the inferred soil type had similar properties to what was actually there. When the predicted soil type was combined with the predicted moisture, the bearing strength measurement of the soil met the KPP requirements.

From the user aspect, there were two major software related concerns. The first is that the OLS-MS, OLS-EVM, and FASST modules all exist as independent software packages and are not integrated. The second concern is that the user interface of the three software modules is only usable to computer science specialists who understand programming environments. These facts lead to logical recommendations concerning maturation of the technologies demonstrated into an eventual fielded system. Overall, the software performed extremely well and showed its value in future pursuits in the area of finding natural terrain landing sites.

5.1.3. OLS Strengths/Benefits

The OLS System has completed its program with good results. Scientific principles were examined, and the program pushed the envelope in technologies heretofore not recognized. It was demonstrated that it was possible to determine potential landing sites without having “boots on the ground” in dangerous clandestine operations. Alternatively, the system can narrow the possible choices of OLSs before a STT is deployed. The OLS system is not complete, nor is it one hundred percent reliable in predicting soil strength. Further, in its present state, the software is neither fully integrated nor user friendly. Nevertheless, the basic required OLS functionality has been implemented in the software, and the core capability may be built upon to provide additional information concerning, for example, drop zones or marshalling areas.

5.2. Recommendations

It is recommended that this important program move to the next logical step, transitioning to a solid, usable technology. With proper funding and the right team, the next OLS program should be able to utilize the excellent results from this program’s demonstrations to add to and focus the software code, integrating the modules into a single, user-friendly suite capable of being utilized either by AMC or another agency to return the answers warfighters need in mission planning.

With no follow on activity planned, AFRL with inputs from Boeing and ERDC-CRREL, developed a technology maturation plan that describes logical follow-on tasks. It recommends (and provides some alternative ideas) for the next steps to mature OLS software for development. Further details can be found in the actual Technology Maturation Plan (reference A1.3 in the annotated bibliography).

Appendix A: Annotated Bibliography

A.1 Final Reports

A.1.1 Boeing Final Report

Citation: Almassy, Richard, Hines, Corrisa, Blake, Dr. Pam, and Baker, Dr. Ralph. 2007. *Opportune Landing Site Final Report*, AFRL-RB-WP-TR-2008–3017: 120 pp.

Available through DTIC Distribution C. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis

A.1.2 ERDC Final Report

Citation: Ryerson, Charles C., Shoop, Sally A., and Koenig, George G. 2007. *Opportune Landing Site Program: Final Report*, ERDC/CRREL TR-08-13: 184 pp.

Available through DTIC or from CRREL, Distribution B. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

A.1.3 AFRL Technology Maturation Plan

Citation: Rufa, Justin, Eizenga, Kenneth, McCarty, Robert, Ventresca, Carol, Almassy, Richard, and Ryerson, Dr. Charles. 2008. *Opportune Landing Site Technology Maturation Plan*, AFRL-RB-WP-TR-2008–3064: 82pp

Available through DTIC Distribution C. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

A.2 Field Test Reports (CRREL and Syngenics)

A.2.1 Indiana OLS Analysis

Citation: Barna, Lynette A., Ryerson, Dr. Charles C., Affleck, Rosa T., Claffey, Keran J., and Tracy, Brian T. 2007. *Opportune Landing Site Southeastern Indiana Field Data Collection and Assessment.* ERDC/CRREL TR-08-22: 290 pp.

Available through DTIC or from CRREL, Distribution A. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: This report focuses on the ERDC evaluation of the capability of Boeing OLS software for reliably locating suitable OLSs, data collected in order to provide the capability to predict soil moisture with depth, and data collected in order to provide the capability of predicting soil strength. Although the end state in 2007 will not be a full operational capability, it will demonstrate the capabilities of current technology in a semi-integrated functional demonstration package. This was accomplished by conducting field work at CONUS locations selected by the

Boeing OLS software according to criteria described in Section 2 of this report. Specifically, ERDC's goals were to establish whether OLSs selected by the software met criteria established by the AFCESA for contingency airfields, but modified for opportune landing sites. The AFCESA criteria, created jointly by the Air Force and the USACE, provide requirements for 16 paved and unpaved runways regarding suitability for various types of aircraft, loadings, and number of operations (AFCESA, 2002). Ultimately, ERDC conducted field work at four locations; El Centro Naval Air Facility in southern California, Ft. Bliss in New Mexico (Affleck et al., 2007), and two locations in southern Indiana (Barna et al., 2007). This report describes field work conducted at the sites located in southern Indiana, and provides a seasonal assessment of the suitability of the software-selected OLSs, and a RAS, identified by the software for potential use as a viable landing site.

A.2.2 Ft Bliss OLS Analysis

Citation: Affleck, Rosa T., Ryerson, Dr. Charles C., Barna, Lynette, and Claffey, Keran. 2007. *The Opportune Landing Site Program: Fort Bliss OLS Suitability Measurement and Analysis,* ERDC/CRREL TR-08-16: 364 pp.

Available through DTIC or from CRREL, Distribution A. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: This report focuses on the ERDC evaluation of the capability of Boeing OLS software for reliably locating suitable OLSs, data collected in order to provide the capability to predict soil moisture with depth, and data collected in order to provide the capability of predicting soil strength. Although the end state in 2007 will not be a full operational capability, it will demonstrate the capabilities of current technology in a semi-integrated functional demonstration package. This was accomplished by conducting field work at CONUS locations selected by the Boeing OLS software according to criteria described in Section 2 of this report. Specifically, ERDC's goals were to establish whether OLSs selected by the software met criteria established by the AFCESA for contingency airfields, but modified for opportune landing sites. The AFCESA criteria, created jointly by the Air Force and the USACE, provide requirements for 16 paved and unpaved runways regarding suitability for various types of aircraft, loadings, and number of operations (AFCESA, 2002). Ultimately, ERDC conducted field work at four locations; El Centro Naval Air Facility in southern California, Ft. Bliss in New Mexico (Affleck et al., 2007), and at two locations in southern Indiana (Barna et al., 2007). This report describes field work conducted at the sites located on Ft Bliss, New Mexico, and provides a seasonal assessment of the suitability of the software selected OLSs, and a RAS, identified by the software for potential use as a viable landing site.

A.2.3 El Centro OLS Analysis

Citation: Affleck, Rosa T., Ryerson, Dr. Charles C., Barna, Lynette, and Claffey, Keran. 2007. *The Opportune Landing Site Program: Suitability Measurement and Analysis for El Centro Naval Air Facility OLS,* ERDC/CRREL TR-08-18: 406 pp.

Available through DTIC or from CRREL, Distribution A. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: This report focuses on the ERDC evaluation of the capability of Boeing OLS software for reliably locating suitable OLSs, data collected in order to provide the capability to predict soil moisture with depth, and data collected in order to provide the capability of predicting soil strength. Although the end state in 2007 will not be a full operational capability, it will demonstrate the capabilities of current technology in a semi-integrated functional demonstration package. This was accomplished by conducting field work at CONUS locations selected by the Boeing OLS software according to criteria described in Section 2 of this report. Specifically, ERDC's goals were to establish whether OLSs selected by the software met criteria established by the AFCESA for contingency airfields, but modified for opportune landing sites. The AFCESA criteria, created jointly by the Air Force and the USACE, provide requirements for 16 paved and unpaved runways regarding suitability for various types of aircraft, loadings, and number of operations (AFCESA, 2002). Ultimately, ERDC conducted field work at four locations; El Centro Naval Air Facility in southern California, at Ft. Bliss in New Mexico (Affleck et al., 2007), and at two locations in southern Indiana (Barna et al., 2007). This report describes field work conducted at the sites located near El Centro, California, and provides a seasonal assessment of the suitability of the software selected OLSs, and a RAS, identified by the software for potential use as a viable landing site.

A.2.4 Final Demo Field Test in St. Clair County, IL

Citation: Ventresca, Carol, Althoff, Victoria 2008. *OLS Software Demonstration and validation of capability to identify landing sites and low incidence of false positives.* SynGenics, AFRL-RB-WP-TR-2008–3163 pp.

Available through DTIC, Distribution A. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, natural terrain landing sites.

Abstract: This report focuses on the initial final demonstration test of the OLS software. The testing took place on 5 June 2007 in eastern St Clair County, IL. Comparison and evaluation of OLS sites identified by the Boeing OLS software and sites identified by a former STT trained AMC personnel. Focus was on the ability of the software to identify natural terrain landing areas that were long enough, wide enough, flat enough, heavy vegetation free, standing water free, and free of obstacles to support aircraft operations. Strength of the soil to support aircraft operations were not evaluated.

A.3 CBR Determination/Database Related Reports

A.3.1 OLS Program In Situ California Bearing Ratio Database

Citation: Seman, Peter M. and Shoop, Sally A. 2007. *Opportune Landing Site Program: In Situ California Bearing Ratio Database.* ERDC/CRREL TR-07-21: 97 pp.

Available through DTIC or from CRREL, Distribution A. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: A global database of in situ soil test measurements and associated attributes was compiled for use in developing California Bearing Ratio (CBR) prediction models. From a variety of potential data sources, a collection of U.S. Army and Air Force airfield pavement research and evaluation reports was selected for inclusion. The schema includes data fields for common geotechnical parameters related to airfield pavement strength and geomorphological features associated with soil formation. More than 4,500 records from 46 test sites, representing 10 countries and 4 continents, were gathered and more than 1,500 of these contain field CBR test values. The database includes a wide variety of Unified Soil Classification System (USCS) soil types from a diversity of natural environments. The distribution of the numeric parameters in the database falls within the range of published distributions for natural soils reported in the literature.

A.3.2 OLS Program Field Data Archive

Citation: Scott, Forest, Barna, Lynette, Affleck, Rosa, Claffey, Keran, Ochs, Elke, and Ryerson, Charles. 2007. *Opportune Landing Site Program: Field Data Archive:* ERDC/CRREL TR-08-23: 19 pp.

Available through DTIC or from CRREL, Distribution A. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: Opportune Landing Sites (OLS) are locations where aircraft can land and take off on surfaces unimproved by engineers for aircraft operations. An OLS can be desert, agricultural land, or any other area that is sufficiently large, smooth, flat, free-of obstructions, and sufficiently firm to allow aircraft operations. OLSs are not modified by engineers for aircraft operations, but have characteristics suitable for aircraft operations. The Opportune Landing Site Program, funded by USTC through Air Mobility Command and the Air Force Research Laboratory, assessed the capability of modeling and simulation techniques for locating OLSs and for predicting their strength (Ryerson and McDowell, 2007). ERDC-CRREL's tasks in the program were to evaluate the capability of Boeing software for locating OLSs and to infer the strength of OLS soils. ERDC-CRREL's tasks were accomplished in part through extensive field work in Indiana, New Mexico, and California described in detail by Barna et al. (2008) and Affleck et al. (2008a, 2008b).

This document contains a database created from this field work conducted in 2005 and 2006. The database contents are created from seasonal on-site measurements and from field samples subsequently analyzed in the ERDC-CRREL Soils Laboratory. Data resulting from these activities are organized into structured electronic files in a computer-accessible data archive to provide a common information resource.

A.3.3 OLS Program Trafficability Cone Index Database

Citation: Diemand, D., Shoop S., Mason, G., and Brandon, G. 2007. *Opportune Landing Site Program: Trafficability Cone Index Dataset.* ERDC/CRREL TR-08-2: 72 pp.

Available through DTIC or from CRREL, Distribution A. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: Decisions supporting rapid emplacement of opportune landing zones are based, in part, on the soil conditions in the area. The strength, physical property, and type of surface soil are critical information for use as a design and decision aid. The soil information is often limited or missing and is inferred for historic databases of similar and/or nearby areas. This report is a compilation of supporting soils from over nearly 50 years of trafficability and vehicle mobility studies. Data drawn from these reports includes data fields for common geotechnical parameters related to soil strength and geomorphological features associated with soil formation. More than 14,000 records were included in the database from a wide variety of Unified Soil Classification System (USCS) soil types and from a diversity of natural environments. The data supports inference of missing data, correlations between physical properties of soils, and statistical assertions of some soils models.

A.3.4 OLS CBR and Low Density Laboratory Database

Citation: Danyluk, Larry S., Shoop, Sally A., Affleck, Rosa T., and Wieder, Wendy. 2008. *Opportune Landing Site CBR and Low-Density Laboratory Database.* ERDC/CRREL TR-08-9: 100 pp.

Available through DTIC or from CRREL, Distribution A. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: Current United States (US) Army and Air Force (USAF) procedures for the planning and design of airfields in Theater of Operations (TO) entail several steps (Field Manual (FM) 5-430-00-2, Vol. II, 1994). For an unimproved or expedient-surfaced airfield, proposed sites of the proper size and geometry must be located, the design aircraft with its associated gross weight selected, and in-place soil strength measured. For most military applications, the soils' California Bearing Ratio (CBR) is used as an empirical measurement of shear strength. CBR, obtained either through laboratory or field testing, is used with empirical curves to determine if the soils at the site can support aircraft operational loads.

Under the Opportune Landing Site (OLS) program, a joint industry/Department of Defense (DoD) initiative, efforts are underway to develop mapping software what utilizes commercially available Landsat imagery to remotely locate unimproved landing sites for military aircraft in natural terrain. Currently available Landsat photography can identify areas that are sufficiently flat, and absent of heavy vegetation, obstacles and surface water, to land an aircraft, perform off-load and on-load operations, and then take off, real time weather conditions permitting, This would eliminate the need for advance on-ground reconnaissance to locate potential sites. However, to date, soil strength or bearing capacity of potential landing sites has only been identified by advanced military personnel on the ground, performing standard field soil bearing tests, prior to the beginning of aircraft operations. In non-hostile environments, specially trained civil engineer personnel conduct these evaluations. In hostile situations, combat control teams conduct the evaluations under clandestine conditions. There are several constraints to the current methods, including compromising the location itself, and danger to personnel performing the evaluations in hostile environments.

A.3.5 OLS Program: Predicting California Bearing Ratio from Trafficability Cone Index Values

Citation: Shoop, Sally A., Diemand, Deborah, and Wieder, Wendy L. 2007. *Opportune Landing Site Program: Predicting California Bearing Ratio from Trafficability Cone Index Values*. ERDC/CRREL TR-08-17: 121 pp.

Available through DTIC or from CRREL, Distribution A. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: Current United States (US) Army and Air Force (USAF) procedures for the planning and design of airfields in Theater of Operations (TO) entail several steps (Field Manual (FM) 5-430-00-2, Vol. II, 1994). For an unimproved or expedient-surfaced airfield, proposed sites of the proper size and geometry must be located, the design aircraft with its associated gross weight selected, and in-place soil strength measured. For most military applications, the soils' California Bearing Ratio (CBR) is used as an empirical measurement of shear strength. The measured CBR is then used with empirical curves to determine if the soils at the site can support aircraft operational loads.

Efforts are underway to develop mapping software what utilizes commercially available Landsat imagery to remotely locate unimproved landing sites for military aircraft in natural terrain. Areas that are sufficiently flat, and absent of heavy vegetation, obstacles and surface water to land an aircraft and, real time weather conditions permitting, perform off-load and on-load operations, and then take off, can be identified from currently available Landsat imagery. This would eliminate the need for advance on ground reconnaissance to locate potential sites. However, to date, soil strength or bearing capacity of potential landing sites has only been identified by advance military personnel on the ground, performing standard field soil bearing tests, prior to the beginning of aircraft operations. In non-hostile environments, specially trained civil engineer personnel conduct these evaluations. In hostile situations, combat control teams conduct the evaluations under clandestine conditions. There are several constraints to the current methods, including compromising the location itself, and danger to personnel performing the evaluations in hostile environments.

Compounding the difficulty of physically taking soil strength measurements in the field is the method of testing. Standard CBR laboratory testing requires sampling, transport of soils to a laboratory, and then a four-day testing period. Field CBR tests are also time-consuming to run and are impractical for use in the TO. Therefore it is the standard practice of the USAF to determine strength using a dynamic cone penetrometer (DCP), and then correlate the DCP readings to a CBR value for use in the empirical evaluation method. On the other hand, when the US Army evaluates or predicts ground strength for vehicle operations a trafficability cone index (CI) is used. Measurements and predictions of trafficability CI are common for Army terrain analysis and for modeling and simulations of ground-based operations; therefore relating CI to CBR is useful for tapping into this additional resource. This report presents correlations between CI and CBR based on USCS soil classification or gross soil descriptions and documents the methods and data used in the development of these relationships.

A.3.6 Soil Strength Prediction with Machine Learning Methods

Citation: Seman, Peter M. A. 2006. *Generalized Approach to Soil Strength Prediction with Machine Learning Method.* ERDC/CRREL TR-06-15: 152 pp.

Available through DTIC or from CRREL, Distribution A. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: Current methods for evaluating the suitability of potential landing sites for fixed-wing aircraft require a direct measurement of soil bearing capacity. In contingency military operations, the commitment of ground troops to carry out this mission prior to landing poses problems in hostile territory, including logistics, safety, and operational security. Developments in remote sensing technology provide an opportunity to make indirect measurements that may prove useful for inferring basic soil properties. However, methods to accurately predict strength from other fundamental geotechnical parameters are lacking, especially for a broad range of soil types under widely-varying environmental conditions. To support the development of new procedures, a dataset of in situ soil pit test results was gathered from airfield pavement evaluations at forty-six locations worldwide that encompass a broad variety of soil types. Many features associated with soil strength—including gradation, moisture content, density, specific gravity and plasticity—were collected along with California Bearing Ratio (CBR), a critical strength index used to determine the traffic loading that the ground can support. Machine learning methods—with advantages in nonlinear relationship mapping, nonparametric distribution treatment, superior generalization, and implicit modeling— were applied. Hypothesizing these characteristics might make them better-suited to geotechnical problems. Artificial neural network and *k*-nearest neighbor techniques were tested on plastic and non-plastic subsets of data and compared to conventional regression and existing CBR prediction methods. The machine learning models were able to halve the baseline error rate for plastic soils, but non-plastic soils showed no significant improvement. For both groups, normalized root mean square error (NRMSE) for generalization to new cases was approximately fifty percent for the best models. The high degree of variability for direct soil strength measurement methods limits the lowest possible NRMSE to approximately twenty-five percent, even before introducing any additional errors expected with remote sensing.

A.4 FASST Related Reports

A.4.1 FASST Description Report

Citation: Frankenstein, Susan and Koenig, George. 2004. *Fast All-Season Soil Strength (FAAST)*. ERDC/CRREL SR-04-1: 107 pp.

Available through DTIC or from CRREL, Distribution A. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: The ability to predict the state of the ground is essential to manned and unmanned vehicle mobility and personnel movement, as well as determining sensor performance for both military and civilian activities. As part of the Army's Battlespace Terrain Reasoning and Awareness research program, the 1-D dynamic state of the ground model FASST (Fast All-Season Soil STrength) was developed. It calculates the ground's moisture content, ice content, temperature, and freeze/thaw profiles, as well as soil strength and surface ice and snow accumulation/depletion. The fundamental operations of FASST are the calculation of an energy and water budget that quantifies both the flow of heat and moisture within the soil and also the exchange of heat and moisture at all interfaces (ground/air or ground/snow; snow/air) using both meteorological and terrain data. FASST is designed to accommodate a range of users, from those who have intricate knowledge of their site to those who know only the site location. It allows for

22 different terrain materials, including asphalt, concrete, bedrock, permanent snow, and the USCS soil types. At a minimum, the only weather information required is air temperature.

A.4.2 FASST Vegetation Models

Citation: Frankenstein, Susan and Koenig, George. 2004. *FAAST Vegetation Models*, ERDC/CRREL TR-04-25: 56 pp.

Available through DTIC or from CRREL, Distribution A. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: The one-dimensional dynamic state of the ground model FASST (Fast All-Season Soil Strength) is a state of the ground model developed by Frankenstein and Koenig (2004) as part of the Army's Battlespace Terrain Reasoning and Awareness (BTRA) research program. In its original form, the only effects vegetation had on FASST were to change the surface albedo and emissivity. Recently, a two-tier, multilayer vegetation algorithm was added. These can be implemented separately or together. Both alter the soil surface energy and moisture budgets. In this report, the energy balance equations used to solve for the low vegetation, canopy and ground temperatures are discussed. In solving these equations, the effects of precipitation interception and soil moisture modification attributable to root uptake are incorporated.

A.5 Automated Validation Related Report

A.5.1 A GIS Approach for Validation

Citation: Ryerson, Dr. Charles C., Scott, Forrest R., and Tracy, Brian T. 2008. *Opportune Landing Site Program: GIS-based OLS Suitability Assessment.*, ERDC/CRREL TR-08-4: 83 pp.

Available through DTIC or from CRREL, Distribution A. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: Verification of the quality of opportune landing sites (OLS) is a key process for assessing their safety prior to use. Verification examines the quality of information used in and conclusions drawn from imagery and map analysis processes. Separate checks on modeling inferences and predictions using sources of information independent of the OLS prediction models provide a measure of confidence regarding the quality of OLS predictions.

Operationally, Air Force Special Operations Command routinely checks the quality of proposed OLSs located using remotely sensed and traditional mapped information. Teams are then placed on the ground to reassess site geometry, such as flatness, smoothness, and freedom from obstructions and to measure soil strength since it is not obtainable from imagery. These operations are time-consuming and can place personnel at risk.

A role of ERDC in the OLS demonstration program was to verify the capability of the Boeing Opportune Landing Site – Multispectral Software (OLS-MS) for locating large, smooth, flat, obstruction-free areas (Ryerson and McDowell, 2007). In that regard, ERDC evaluated the quality of four field sites at three geographic locations; southern Indiana, Ft. Bliss, and El Centro Naval Air Facility. Four sites were chosen by the OLS program to add to four sites used by Boeing for independent evaluation of the OLS software using Internal Research and Development

(IRAD) funds prior to the start of the OLS demonstration program (Vincent and Jennings, 2004). Four or eight sites, however, do not make statistically significant samples, being too small to allow the drawing of broad conclusions regarding software capability. In addition to the small sample size, gathering information in the field is labor intensive, slow, and expensive. Creating a statistically significant sample using manual methods would not be possible because of the need to obtain landowner permission to access the land. The only other alternative currently considered would be the use of low-flying aircraft to inspect OLSs.

The goal of this report is to assess a Geographic Information System (GIS)-based approach for evaluating the quality of OLSs. GISs are analysis tools, allowing the integration of spatial information of a variety of formats to answer a variety of spatial questions. In this case, a methodology is presented for using the GIS to assess the intersection of OLSs with mapped obstructions. The capability of the process, and of the OLS software, will be illustrated from results in 26,000 km2 areas of southeastern Indiana, southeastern New Mexico, and southeastern California.

A.6 Conference Papers

A.6.1 - 2006 Program Overview

Citation: Ryerson, C. and McDowell J. 2007. “Anywhere-anytime: Enhancing Battlespace Vertical Mobility.” Presentation at the AIAA 45th Aerospace Sciences Meeting and Exhibit, Reno NV, AIAA #2007-1103: 9 pp.

AIAA 45th Aerospace Sciences Meeting and Exhibit, 8-11 January, 2007, Reno. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: Rapid locating of opportune landing sites that are smooth, flat, firm, and free of obstructions would be a great advantage for fixed wing and rotary wing aircraft needing to land where no formal runways are established. AFRL, ERDC, and industry have partnered to demonstrate technologies that may provide this capability. Industry is providing software for locating OLSs using Landsat imagery, software for identifying soil type, and the skills to integrate algorithms from all partners into an efficient software tool. ERDC-CRREL is evaluating the software capability on the ground, providing soil moisture prediction tools, and providing robust soil strength prediction algorithms. AFRL is managing the program and assisting with developing a final demonstration with AMC.

A.6.2 Soil Strength Prediction with K-Nearest Neighbor Method

Citation: Seman, P., Shoop, S., McGrath, S., and Rollings, R. 2006. “Soil Strength Prediction with K-Nearest Neighbor Method.” Presentation at the 59th Canadian Geotechnical Conference, Vancouver, BC: 7pp.

Available through DTIC or from CRREL, Distribution A. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: Evaluating landing sites for fixed-wing aircraft currently requires direct measurement of soil bearing capacity, but remote sensing may provide a means to infer other basic geotechnical properties. However, methods to accurately predict strength from these are lacking, especially for

diverse soil types under widely varying environmental conditions. To support the development of new strength prediction techniques, a dataset of in situ soil pit test results was gathered from airfield pavement evaluations encompassing many USCS soil types. Features associated with California bearing ratio (CBR) were compiled, including gradation, moisture content, density, specific gravity, and plasticity. A case-based reasoning approach was used to implicitly "learn" from examples and make predictions of CBR. Nearest neighbor models halved baseline error rates for plastic soils, but provided no benefits for non-plastic. The lowest normalized root mean square error for generalization to new cases was approximately fifty percent, double the theoretical limit due to inherent soil variability.

A.6.3 - 2007 Program Overview

Citation: Ryerson, C., McDowell, J., Almassy, R., Walker, D., and Eizenga, K. 2008. "The Opportune Landing Site (OLS) Program." Presentation at the Transportation Systems Workshop, Phoenix, AZ #2008-79: 13 pp.

2008 Transportation Systems Workshop: The Search for Opportune Landing Sites. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: None. Introduction: Since the end of the Cold War, warfare has evolved to require rapid response to a wide variety of adversaries. In this regard, General Shinseki (retired Army Chief of Staff), when developing his vision of the Future Force and the Future Combat System (FCS), indicated that combat must be initiated on U.S. terms at a time and place and with a method of U.S. choosing. This responsiveness requires rapid deployment, agility, and versatility—capabilities provided by aviation.

Aircraft, especially fixed wing transports, are typically restricted with regard to where to land, generally requiring prepared runways. An ability to operate out of unprepared fields allows greater flexibility than is now available. Such a capability could dramatically change strategy, and would increase tactical OPTEMPO. However, locating large, smooth, flat, obstruction-free, and firm unprepared places to land aircraft is currently a relatively slow, manual process requiring confirmation by placing soldiers on the ground, often in threatening situations. To improve this capability, the U.S. Transportation Command funded the Opportune Landing Site (OLS) Program to determine the current technological capability of locating OLSs automatically using available imagery, map and weather information. This report describes the goals and technical elements of the OLS program.

A.6.4 - 2007 Requirements Generation

Citation: Ventresca, C., McDowell, J., Walker, D., Almassy, R., and Ryerson, C. 2008. "Establishing Evaluation Criteria for an OLS System." Presentation at the Transportation Systems Workshop, Phoenix, AZ #2008-108: 16 pp.

2008 Transportation Systems Workshop: The Search for Opportune Landing Sites. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: If you don't know where you want to go, it's difficult to choose the best path or to recognize the destination when you reach it. Developing a clearly defined set of evaluation criteria early in a program helps program management set the course, measure progress, and

improve the likelihood for success. On the OLS System Validation and Demonstration Program, performed 2004–2007, the product was software capable of locating smooth, flat, firm, obstruction-free OLSs. AFRL, ERDC, Boeing, and SynGenics applied a process that provides a structured approach and consistent framework for defining success, achieving consensus in decision making, and maximizing probability of success. The process begins with capturing quantified evaluation criteria that define what the product must do, as well as the nice-to-have aspects. The term *desirements* is used to describe the set of evaluation criteria, defined in appropriate units of measure and mapped to the desirability scale. The must-haves comprise the subset called Exit Criteria. The evaluation criteria thus defined form the multi-dimensional solution space that characterizes the optimal system. Applying the process early in the OLS System Validation and Demonstration Program clarified objectives, supported program decisions, and diminished the effort expended on features USTC did not consider important. The result was a set of clearly defined desirements for three critical points in OLS System evolution that removed ambiguity and supported the integrated program plan for the realization of a tool to give the warfighter access anywhere in the battlespace by 2030, despite the absence of prepared landing strips.

A.6.5 - 2007 Boeing Accomplishments

Citation: Blake, P. and Almassy, R. 2008. “Opportune landing site: Boeing Accomplishments.” Presentation at the Transportation Systems Workshop, Phoenix, AZ #2008-3: 10 pp.

2008 Transportation Systems Workshop: The Search for Opportune Landing Sites. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: None. Introduction: United States (US) joint military doctrine requires US military forces to be highly mobile and capable of rapid global response to effect a wide range of military options. As US forces become more expeditionary in nature, there is an increasing dependence on air transportation for rapid deployment and effective, efficient sustainment. Inherent in this expeditionary concept is the requirement to be able to conduct military operations with minimal or no reliance upon foreign airports. The need to conduct airlift operations to other than existing runways has been a critical enabler in the Global War on Terror (GWOT). These operations involve landing on semi-improved or austere airfields and can include forced-entry options and combat resupply of engaged troops. To provide this capability, US forces must be able to accurately determine the suitability of a proposed site. Today this determination relies almost exclusively upon a STT visiting the location and assessing the proposed site before airlift operations begin. While a site survey provides an accurate assessment, it is a time consuming process, inherently dangerous and one that can compromise future operations if the presence of a STT is detected. The Opportune Landing Site (OLS) program was started to provide a means to assess the suitability of a given site through the use of remote sensing technology without having to rely on a STT.

Boeing and the US Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) submitted a white paper to the Air Force Research Laboratory (AFRL) in May 2003. This white paper proposed using Boeing satellite imagery analysis software and CRREL terrain modeling software to locate and evaluate natural terrain landing sites. AFRL gave the white paper to AMC, which decided to fund the proposal. AFRL was selected to manage the program and separately contracted with Boeing and CRREL to develop an automated OLS capability.

The OLS software applications were intended to be used primarily as military airlift mission planning tools. They are currently in a developmental state consisting of three discreet modules of computer coded algorithms. The first two modules were developed by Boeing, the third module was developed by CRREL. The first module, OLS-MS, uses pixilated satellite imagery to identify candidate landing areas that are flat and clear of obstructions, standing water and heavy vegetation. The second module, OLS-EVM, uses pixilated satellite imagery and digital terrain elevation data (DTED) to determine soil type. The third module, Fast All-Season Soil State (FASST), uses weather data and soil type to determine soil moisture content and infer California Bearing Ratio (CBR). Field demonstrations to validate the performance of the applications were conducted throughout the summer, 2007.

A.6.6 - 2007 Assessment of OL Sites in Southeastern Indiana

Citation: Barna, L. A., Ryerson, C. C., and Affleck, R. T. 2008. “Assessment of Opportune Landing Sites in Southeastern Indiana.” Presentation at the Transportation Systems Workshop, Phoenix, AZ #2008-11: 22 pp.

2008 Transportation Systems Workshop: The Search for Opportune Landing Sites. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: None. Introduction: Effectiveness in modern warfare requires response to a wide variety of adversaries rapidly, lethally and often times stealthily. The Army’s Future Combat System (FCS) relies upon agility and speed as components of its operating philosophy. This requires, in part, the ability to conduct air transport operations to locations where there are no existing runways, and where engineers cannot be pre-positioned due to either time constraints or the need for surprise. One of the most difficult problems is locating Opportune Landing Sites (OLSs), characterized as large, smooth, flat and obstruction-free areas that are also sufficiently firm to support at least one aircraft operation, and preferably many. Several new approaches have been taken to improve the capability of rapidly locating OLSs using satellite imagery (Manley 2001; Vincent and Jennings 2004; and Ryerson and McDowell 2007). The OLS program, managed by the Air Vehicles Directorate at the Air Force Research Laboratory (AFRL/VA) at Wright-Patterson Air Force Base, in partnership with the U.S. Army Corps of Engineers, Engineer Research and Development Center (USACE-ERDC) and The Boeing Company, has applied existing technologies to rapidly accelerate the process of selecting OLSs using remote sensing technology and state-of-the-ground forecast tools (Ryerson and McDowell 2007). Boeing has developed a software program that identifies OLSs using Landsat imagery. The current OLS program has three goals. One goal is to evaluate the quality of the OLS software to locate smooth, flat, level, obstruction free areas for landing zones using multi-spectral Landsat imagery. The second goal is to evaluate the capability of the OLS software to locate OLSs in any season. The third goal is to evaluate the OLS software for its ability to locate firm landing zones, since Boeing found an association between selected OLSs and soil firmness in early field verifications of the software. In this study, the goals of the ERDC were to establish whether OLSs selected by the software were capable of supporting operations by military transport aircraft. Criteria currently established by the Air Force Civil Engineer Support Agency (AFCESA) to assess contingency airfields, were applied and modified, as needed, to evaluate OLSs. The AFCESA criteria, created jointly by the Air Force and the USACE, provided requirements for paved and unpaved runways regarding suitability for various types of aircraft, loadings, and number of operations (AFCESA 2002). Additional details of the project are reported in Barna, et al (in review).

A.6.7 - 2007 Assessment of OL Sites at El Centro NAF and Fort Bliss

Citation: Affleck, R. T., Ryerson, C. C., and Barna, L. A. 2008. "Assessment of Opportune Landing Sites at El Centro NAF and Fort Bliss." Presentation at the Transportation Systems Workshop, Phoenix, AZ #2008-1: 21 pp.

2008 Transportation Systems Workshop: The Search for Opportune Landing Sites. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: To evaluate the quality of the selected Opportune Landing Sites (OLSs), ground truth activities were conducted at El Centro Naval Air Facility in southern California and at Ft. Bliss in New Mexico; and procedures for evaluating these locations are described in this report. Prior to conducting field measurements, several OLSs identified by the OLS software were inspected at each site to visually evaluate the OLSs and to down-select a suitable OLS for field testing from an extensive list of possible locations. In addition to having no obvious obstructions, the primary consideration for selecting an OLS at each site was logistic; ready access for field work and safety of personnel in an active military training environment.

Field measurements assessed smoothness, flatness, freedom from obstructions and, most importantly, the soil strength of the OLS. Some evaluation procedures were modified from Air Force Civil Engineering Support Agency (AFCESA) recommendations for evaluating airfield pavements. Other procedures were modified because measurements were being made in weak natural soils. In addition, the dry, cemented, and caliche-laden soils found in these arid environments required modification of traditional engineering field and analysis methods. Soil type and density profiles were determined from soil pits excavated at selected locations on the OLS. Soil strength and soil moisture measurements were made on several locations along the OLS and the overall quality of the OLSs were evaluated during three seasons. Arid environments typically yield the largest number of potential OLSs because of the small amount of vegetation. However, measurements show that surface condition and soil properties are critical factors limiting the potential of OLSs to support aircraft operations in arid climates.

A.6.8 - 2007 CBR Database for Soil Strength Prediction

Citation: Shoop, S. A., Seman, P. M., Diemand, D., Mason, G. L., and Danyluk, L. S. 2008. "California Bearing Ratio Database for Soil Strength Prediction." Presentation at the Transportation Systems Workshop, Phoenix, AZ #2008-87: 20 pp.

2008 Transportation Systems Workshop: The Search for Opportune Landing Sites. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: This paper briefly describes a high-quality soil strength database developed as part of the Opportune Landing Site (OLS) program, but with a range of applicability far beyond its original purpose, such as providing a valuable resource for researchers and engineers to develop new methods and algorithms for predicting soil strength. The database was carefully designed to ensure that as much strength data as feasible, along with associated parameters, were incorporated, and that later expansion to include additional soil measurements related to soil strength, including geographic and geomorphological information, could be accommodated.

Soil strength can be defined and measured in many ways. For the Opportune Landing Site program, only CBR strength was considered in order to be applicable to current airfield design methodology and experience and historical data. Only high-quality, true CBR measurements were included in the database (no derived measurements). However, despite this emphasis on CBR in the interest of the OLS program, other data are included in the database, notably extensive Cone Index data.

The database is composed of four separate but related datasets and was generated in stages over several years. It includes primarily three data sources; 1) high quality field CBR measurements taken as part of the USAF airfield evaluation program, 2) measurements from an extensive laboratory program to evaluate the effects of fines,
compactive effort and specifically low density soils, which are presented as two separate datasets, and 3) a dataset of field measurements of CBR taken in conjunction with vehicle mobility and trafficability studies. This third section of the database includes primarily natural, un-engineered soils, likely to be similar to OLS surface materials, and also included corresponding Cone Index measurements enabling calibrating CBR against Cone Index for use in evaluating cone index strength prediction methods. In all, these datasets include roughly 20,000 entries.

A.6.9 Machine Learning Approaches to CBR Prediction for Unsurfaced Airfields

Citation: Seman, P. M. 2008. “Machine Learning Approaches to CBR Prediction for Unsurfaced Airfields.” Presentation at the Transportation Systems Workshop, Phoenix, AZ #2008-81: 16 pp.

2008 Transportation Systems Workshop: The Search for Opportune Landing Sites. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: None. Introduction: Current methods for evaluating potential landing sites for fixed wing military aircraft require a direct measurement of soil bearing capacity be made prior to landing. Efforts are underway to develop mapping software that utilizes commercially available Landsat imagery to remotely locate unimproved landing sites for aircraft in natural terrain (Vincent and Jennings 2004; Ryerson and McDowell 2007). By analyzing satellite data to detect areas that are flat, unobstructed, low vegetation, and firm, the goal is to select suitable areas based on indirect measurements only.

The spectral characteristics of soil determined via remote sensing reportedly can provide insights into some important physical properties at the ground surface that are important contributors to strength, such as grain size, organic matter, moisture content, and mineralogy (Jensen 2000). However, even with direct in situ measurements of such parameters, the ability to accurately predict soil strength from them is tenuous at best. Sometimes, on a site by site or even soil by soil basis, acceptable correlations of soil strength with other soil properties can be made. However, for predictions across a widespread region of interest more generalized relationships are lacking.

Soil strength is a critical factor when determining whether potential landing zones are suitable for supporting aircraft traffic loads. The California Bearing Ratio (CBR) remains the fundamental design method used to evaluate unsurfaced and flexible pavement structures for contingency airfield use. However, few pedotransfer relationships exist to predict CBR from other soil measurements, especially generalized models applicable to the wide range of soil types and conditions encountered in engineering practice worldwide during military operations.

The focus of the research was to determine whether advancements in the application of machine learning techniques by the data mining community for modeling complex phenomena could improve the ability to accurately predict the California Bearing Ratio (CBR) soil strength index from other soil properties on a widespread basis. Approaches based on artificial intelligence (AI) appear particularly well suited to geotechnical applications, with advantages in handling nonlinear behavior, interactions among parameters, uncertainty, and imprecision (Toll 1996a). While there has been some success using these methods to predict CBR and other soil strength indices for specific soils in very limited geographic locations (e.g., Attoh-Okine 2004), application to a wide variety of soils representative of worldwide conditions has not been attempted. Furthermore, the reliability associated with most soil strength prediction methods and the fundamental limitations on the degree of accuracy that is theoretically possible with any method have received little attention to date. Consequently, the efforts were concentrated on evaluating the performance of these new methods in terms of their generalization error, in effect, how well they perform on unseen data not used in the model-building process.

A.6.10 Laboratory CBR Studies of Opportune Landing Sites Soils

Citation: Danyluk, L. S., Affleck, R. T., Shoop, S. A., and Wieder, W. L. 2008. "Laboratory CBR Studies of Opportune Landing Sites Soils." Presentation at the Transportation Systems Workshop, Phoenix, AZ #2008-21: 20 pp.

2008 Transportation Systems Workshop: The Search for Opportune Landing Sites. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: None. Introduction: Current United States (US) Army and Air Force (USAF) procedures for the planning and design of airfields in Theater of Operations (TO) entail several steps (Field Manual (FM) 5-430-00-2, Vol. II, 1994). For an unimproved or expedient-surfaced airfield, proposed sites of the proper size and geometry must be located, the design aircraft with its associated gross weight selected, and in-place soil strength measured. For most military applications, the soils' California Bearing Ratio (CBR) is used as an empirical measurement of shear strength. CBR, obtained either by laboratory or field testing, is used with empirical curves to determine if the soils at the site can support aircraft operational loads.
However, to date, soil strength or bearing capacity of potential landing sites has only been identified by advanced military personnel on the ground, performing standard field soil bearing tests. In non-hostile environments, specially trained civil engineer personnel conduct these evaluations. In hostile situations, combat control teams conduct the evaluations under clandestine conditions. There are several constraints to the current methods, including compromising the location itself and danger to personnel performing the evaluations in hostile environments. Thus a major component of the Opportune Landing Sites (OLS) program is the remote determination of soil bearing capacity values for use in the evaluation of potential landing sites, thus eliminating the need for ground reconnaissance prior to aircraft operations.

A.6.11 Determining USCS Soil Classification from Multi-Spectral Signature

Citation: Hines, C. L. and Wolboldt, M. W. 2008. "Predicint Soil Type From Remotely Sensed Data." Presentation at the Transportation Systems Workshop, Phoenix, AZ #2008-41:13 pp.

2008 Transportation Systems Workshop: The Search for Opportune Landing Sites. Key words: Multispectral, DTED, Decision Trees, USCS soil classification.

Abstract: In 1995, Boeing had a need to quantify the amount of natural terrain areas available to land and takeoff military transports from "opportune landing sites" (OLS). Boeing contracted with BG Image and LLC, to use satellite imagery to determine the natural availability of OLS areas. Part of that analysis was predicting soil hardness, which required knowledge of soil type. Boeing developed a methodology to predict USCS soil classification under contract to the Air Force Research Laboratory. The methodology uses spectral and spatial signature from Landsat satellite imagery and level 2 Digital Terrain Elevation Data (DTED). Boeing developed this method using multi-layered imagery data obtained from processing Landsat imagery and DTED files and using decision tree logic to predict USCS soil classification for surfacial and subsufacial soil layering. This paper will describe how Boeing developed this technique, the imagery processing steps (computing surfacial reflectance, determining soil characteristics, computing band derivatives, computing thermal inertia, etc.) used in the process, and the DTED processing steps (elevation, slope, drainage, etc.) used in the process to predict the soil classification. It will also describe the decision tree logic used to isolate the discriminate variables associated with each soil class, the key enabler in determining the various classification types. It will follow the chronological development from its inception to the program end in 2007.

A.6.12 Physics-Based Model for Predicting State-of-the-Ground for OLS

Citation: Koenig, G. and Frankenstein, S. 2008. "Physics-based Model for Predicting State-of-the-Ground for OLS." Presentation at the Transportation Systems Workshop, Phoenix, AZ #2008-50: 18 pp.

2008 Transportation Systems Workshop: The Search for Opportune Landing Sites. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: The capability to deliver cargo and equipment to austere locations will require landing on semi-improved or austere airfields. The Boeing OLS software application locates and evaluates potential austere landing zones for airlift aircraft using satellite imagery to scan for obstacle free, water free and heavy vegetation free areas. The OLS selected landing zone must also have sufficient strength to support the weight of airlift aircraft. The soil strength is primarily a function of the soil type and the soil moisture. Currently, it is not possible to extract sufficient soil moisture information from satellite data to determine soil strength. Therefore, either in situ measurements or state-of-the-ground models are required to obtain the soil moisture information needed to predict soil strength. In remote locations not controlled by friendly forces it is highly unlikely that in situ measurements will be available. Therefore, physics-based models that predict soil moisture profiles based on knowledge of the soil type and the meteorological boundary conditions are the logical solution. The meteorological boundary conditions are available from the mesoscale models run operationally by the Air Force Weather Agency (AFWA) and the soil type is inferred from satellite data using the Boeing Opportune Landing Site-Extended Vector Method (OLS-EVM) application. Soil moisture is predicted using the physics-based 1-D Fast All-Season Soil Strength (FASST). The soil strength in terms of the California Bearing Ratio (CBR) is determined from the soil type and the soil moisture. Areas that pass threshold values for openness and soil strength represent opportune landing sites. The following sections present

information on: the FASST-OLS model, a comparison of mesoscale and observed weather information for an OLS demonstration site, validation of FASST predicted soil moisture using OLS site information, and a comparison of FASST predicted soil moisture with measured values.

A.6.13 Opportune Landing Site Soil Strength Prediction Demonstration

Citation: Shoop, S. A. Kost, J. M., Ryerson, C. C., Frankenstein, S., Affleck, R., and Buska, J. 2008. “Predicting Soil Strengths for Opportune Landing Sites.” Presentation at the Transportation Systems Workshop, Phoenix, AZ #2008-89: 19 pp.

2008 Transportation Systems Workshop: The Search for Opportune Landing Sites. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: Current evaluations of candidate natural terrain landing zones, airdrop zones, base camp locations, and other military operational areas must be conducted by personnel on-site. There are several constraints to the current methods including overall accuracy of the evaluation tools and techniques, danger to personnel performing the evaluations in hostile environments, individual subjectivity, and weather induced changes in ground strength. The Opportune Landing Site (OLS) Software is intended to alleviate most of these shortcomings by remotely locating OLSs as well as predicting the ability of the surface to support aircraft including weather impacts on soil moisture, temperature, and strength.

At the culmination of the three-year OLS program, a demonstration was performed to showcase the capabilities of the OLS software, demonstrate the current state of the technology, evaluate the potential of the technology for further development and fielding, and identify shortfalls. Because soil strength is a critical factor in assessing whether a location with the proper geometry is also sufficiently firm to support aircraft operations, a major portion of the demonstration aimed to assess the capability to predict soil strength. Four soil strength demonstrations were performed on OLS locations chosen by the Boeing OLS suitability software. Using methodology generated as part of the OLS program, soil classification characteristics, soil moisture and soil strength were predicted to a depth of 1 meter. For ground truth and comparison, Air Force Civil Engineer Support Agency (AFCESA) Air Pavement Evaluation (APE) teams were deployed to the predicted sites to assess the suitability of the OLS and specifically to measure soil strength profiles, soil moisture profiles, soil density (if possible), and soil type profiles to a depth of three feet. This paper presents the results of the prediction and the comparison with field measurements. Conclusions and recommendations for maturation of the technology are given.

A.6.14 OLS Suitability Assessment

Citation: Ryerson, C. C., Tracy, B. T., and Scott, F. R., McDowell, J. 2008. “Opportune Landing Site (OLS) Suitability Assessment.” Presentation at the Transportation Systems Workshop, Phoenix, AZ #2008-80: 19 pp.

2008 Transportation Systems Workshop: The Search for Opportune Landing Sites. Key words: Opportune Landing Site, OLS, remote sensing, landing zones, CBR, natural terrain landing sites, extended vector method, multi-sensor imagery analysis.

Abstract: None. Introduction: Verification of the quality of opportune landing sites (OLS), a key process for assessing their safety prior to use, was a task of ERDC-CRREL in the OLS program (Ryerson et al, 2008). Verification examines the quality of conclusions drawn from imagery and

map analysis processes. Separate checks on modeling inferences and predictions using sources of information independent of the OLS prediction models provide a measure of confidence regarding the quality of OLS predictions.

Initially, ERDC formally evaluated OLS quality by selecting four field sites for intensive field work. Field sites were selected by conducting reconnaissance trips in southern Indiana, New Mexico and southern California. Field sites were located by using the OLS software to predict all prospective OLSs with a specified length, width, and suite of headings (Affleck et al, 2008; Barna et al, 2008). A field team then visited the areas and viewed as many OLSs as reasonably possible by drive-by inspections. In this manner, it was possible to generally inspect each OLS, or clusters of OLSs, by eye from a distance. At some locations it was possible to walk OLSs to assess their quality. For those OLSs that could not be walked it was not possible to accurately or reliably assess the full range of obstructions that may occur on a 915-m long OLS viewed only from one end. As a result, ditches, swales and other features may be missed, though electric lines and fences could often be seen. The drive-by approach did not allow a sufficiently reliable assessment of a large enough number of OLSs to develop a statistically significant analysis of OLS-MS software capability. In addition, obtaining statistically-significant samples in a research environment is generally not feasible because access to private land is often necessary.

Geographic Information Systems (GIS provide tools for efficiently assessing the quality of OLSs in research and operational environments. GISs allow raster or vector data to be overlaid with candidate OLS locations to allow additional evaluation of their quality. GISs could allow mapping of OLS flatness, levelness, soil type, soil moisture, soil strength, and greenness pixel by pixel. In addition, the GIS could be used to evaluate the seasonal and geographic capability of the OLS-MS software in different climates.
This study investigated the use of the GIS to detect OLS obstructions. The study serves as a methodological proof of concept, and also evaluates the capability of the OLS-MS software to locate obstruction-free OLSs in several regions.

Appendix B: Program Development

B.1 Boeing Program Development

The team of AFRL, CRREL and Boeing drafted the technical approach and program schedule shown below as Figure 2.

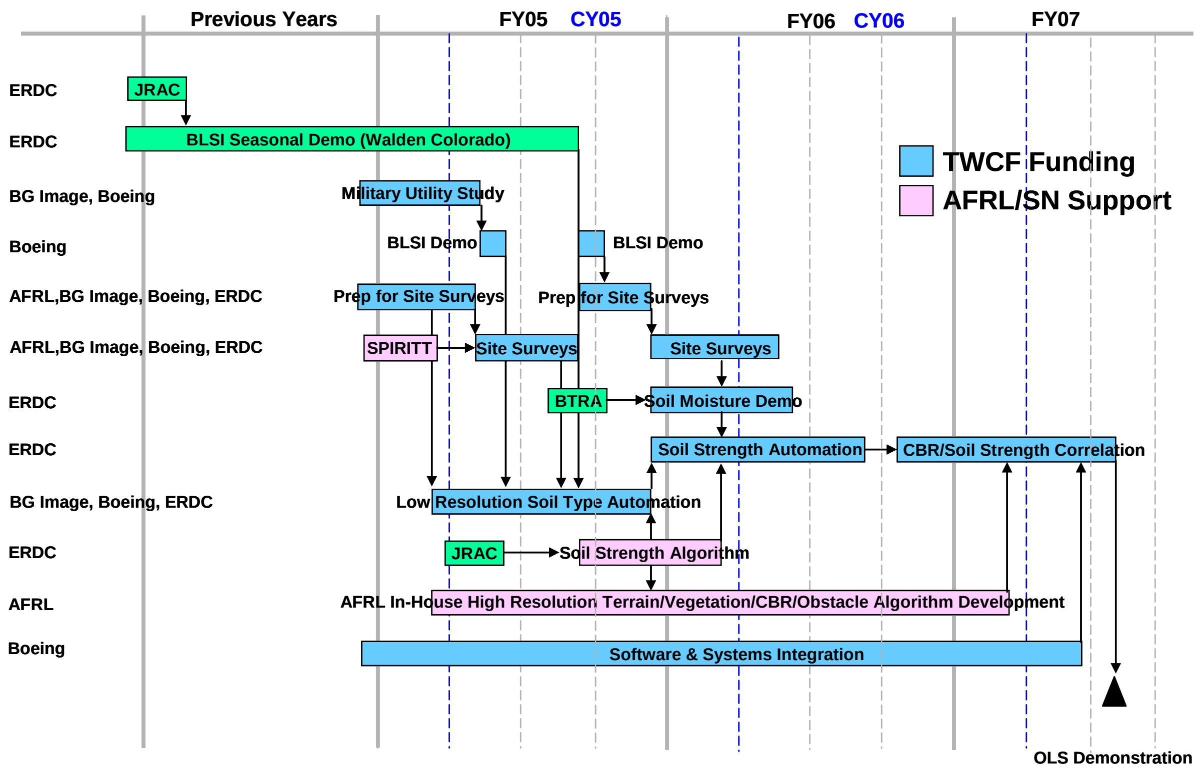

Figure 2. OLS Team Schedule

This initial plan called for a two-phased program. During Phase One, Boeing was to conduct a military utility study (why OLS) and CRREL was to conduct a field evaluation of the previously developed, Boeing proprietary OLS-MS software. During Phase Two, Boeing was to develop soil type algorithms using low resolution imagery (satellite) and CRREL was to develop soil strength algorithms which would predict California Bearing Strength (CBR). In a parallel effort, the AFRL Sensors Directorate (SN) would develop a full site survey capability by modifying an existing algorithm previously developed by them for target recognition, and use high resolution imagery from the SPIRITT airborne sensor under development by SN. AFRL established that the objective of the program was to demonstrate an OLS survey capability with a formal Advanced Technology Demonstration-like field demonstration at the end of the contract period of performance.

The first Boeing task was to conduct a military utility study to quantify the advantages that operating from opportune landing sites provided over operating at fixed airfields only. Table 3 contains the OLS-MS Configuration Control Log for the changes the software underwent during the program. Further detail can be found in Boeing's Final Report, Annotated Bibliography Reference A1.1.

Table 3. OLS-MS Configuration Log

Revision No.	Release Date	Reason for Revision	Description of Revision
OLS-MS_R012505	1/27/2005	Original Release	
OLS-MS_R012805	1/28/2005	Requested by CRREL to read new GeoTIFF format. PM request to report runways in same manner as GUI format.	Input module changed to read *.met.txt header files. Output file changed to output runway length in feet rather than pixels. Output added to report average number of runways over all cardinal headings.
OLS-MS-R020604	2/7/2005	AFRL/SN (Ray Haren) found anomaly in Preferences module. CRREL efficiency suggestions added.	Preference module changed to allot enough RAM to complete program. Added capability to start runway search after BLSI frame created. Added option to not save intermediate files. Output file changed to print text file of all runways. Added BLSI threshold default if user specifies value too low to find runways.
OLS-MS_R021105	2/11/2005	CRREL discovered anomaly reading GeoTIFF formats.	Changed GeoTIFF_Convert module to correctly read *.met.txt formatted imagery.
OLS-MS_R022305	2/13/2005	Boeing discovered false positives in featureless terrain.	Added option to BLSI module to treat vegetation and flatness computations as thresholds rather than averaged index.
OLS-MS_R032605	3/29/2005	Request from CRREL.	Changed output module to include runway start and stop coordinates in runway text file. Changed GeoTIFF_Convert module to read new format. Closed out intermediate file left open. Corrected miscellaneous memory leaks.
OLS-MS_R081606	8/17/2006	Request from AMC/Maj Lambertson and recommendations from NAR	New runway finder which looks for squares of user dimensions. Uses Euclidean vector length to compute gradient image. This removes the dependency on scene statistics.
OLS-MS_031207	3/19/2007	Request from CRREL to perform statistical analysis..	Changed runway finder back to six cardinal headings or user specified headings. Added NASA ACCA cloud recognition filter. Added switches for "vector/PC1" and "Value/Percent" flatness calculations. BLSI no longer computed.

B.2 ERDC Tasks

ERDC-CRREL was assigned five fundamental tasks at the beginning of the OLS program. These were to (1) conduct field evaluations of Boeing OLS-MS software selected sites, (2) provide a soil moisture content prediction demonstration, (3) provide a soil type assessment that evaluated the Boeing ability to infer soil type, (4) demonstrate the capability to infer soil strength, and (5) to conduct a final demonstration. Ultimately, task 3 was accomplished by the Air Force Civil Engineering Support Agency (AFCESA) during the final Demo.

Soil strength prediction was broken into two tasks; to validate algorithms and to develop physics-based algorithms. The latter was basic research and was separated from the soil strength algorithm validation task for administrative reasons—because the primary OLS funding as the program started was for a demonstration of technology, and not for research. Therefore, funds for the physics-based algorithm basic research came from other sources.

A task was added in the third year of the program, to develop a technology maturation plan with Boeing and with AFRL. Its goal was to provide direction for taking the program to

Milestone B-like and Milestone C-like decisions to authorize OLS system development/demonstration and production/deployment respectively. Further detail can be found in ERDC-CRREL's Final Report, Annotated Bibliography Reference A1.2.

B.3 Approach included in AFRL/RY Work

In the summer of 2003, the AFRL's Sensors Directorate advocated the hyperspectral-image-analysis approach to solving the problem of remotely identifying OLSs. The satellite-borne Hyperion hyperspectral IR imaging system, containing 220 contiguous spectral bands and a 30-m pixel size had been proven to resolve spectral data to identify green vegetation, talc, dolomite, chlorite, white mica, and other surface components prior to the start of this effort.[2]

The RY approach was to use hyperspectral imagery obtained from an airborne sensor, which, given the shorter distance above the ground, would provide significantly better resolution than a satellite-borne sensor, and would constitute a better solution. Although the hyperspectral approach was less mature than that taken by the Boeing-led team, AFRL/RY's view was that the presence of 220 contiguous spectral bands promised better results, justifying the risk. The higher number of contiguous spectral bands by virtue of the hyperspectral sensor, and the higher resolution by virtue of the closer proximity of an airborne sensor versus a satellite-borne sensor offered a better means of inferring soil type and, through its use, soil strength.

AFRL/RY's Spectral Infrared Remote Image Transition Testbed (SPIRITT) Advanced Technology Demonstration (ATD) was planned to develop a day/night, long-range reconnaissance imaging testbed that contained a hyperspectral sensor with integrated high-resolution imaging. In the summer of 2004, SPIRITT was testing a near-wave infrared (NWIR) sensor with plans to test a long-wave infrared (LWIR) sensor in 2007. By the winter of 2004–2005, it appeared that calibration trials of an airborne hyperspectral sensor might be conducted. Imagery collected from colored tarps in specified hues placed in different locations would be used to refine the image-processing algorithms in order to produce the desired soil-characterization results leading to determination of soil type and grain size. The SPIRITT flight test was scheduled for the summer of 2005 and was expected to generate soil-trafficability information, determine soil type, mineral/organic content and particle size, and adapt the OLS measure of firmness to a high-spatial-resolution application.

Crucial to the validating the success of the hyperspectral approach was a good knowledge of soils. It was proposed that a significant part of this effort should be expended creating a worldwide soil database. The divergence of opinion about the program's objectives at this point caused some consternation. Through the application of the systems approach to decision making, measurable evaluation criteria were documented, and alternatives approaches were evaluated against these criteria. A result was recognition of the fact that, in addition to the flatness and obstruction-free criteria previously applied to screening for acceptable OLSs, the team finally came to the recognition that a successful OLS system must find locations that are firm enough to support operation.

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[2] Cudahy, T.J.; Hewson, R.; Huntington, J.F.; Quigley, M.A.; Barry, P.S., "The performance of the satellite-borne Hyperion hyperspectralVNIR-SWIR imaging system for mineral mapping at Mount Fitton, SouthAustralia". Geoscience and Remote Sensing Symposium, 2001. IGARSS apos;01. IEEE 2001 International. Volume 1, Issue , 2001 Page(s):314–316 vol.1, Digital Object Identifier 10.1109/IGARSS.2001.976142.

For reasons unrelated to the OLS Demonstration and Validation Program, the sensor never flew and the hyperspectral imaging approach was abandoned in favor of the lower risk multispectral approach.

Appendix C: Opportune Landing System[3] Concept of Operations

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1. Overview. The United States (US) Defense Planning Guidance requires US military forces to be highly mobile and capable of rapid global response to affect a wide range of military options. As US forces become more expeditionary in nature, there is an increasing dependence on air mobility and the Mobility Air Forces (MAF) for rapid deployment and effective, efficient sustainment. Inherent in this expeditionary concept is the requirement to be able to conduct military operations with minimal or no reliance upon indigenous infrastructure. The need to conduct airland operations to other than existing runways is articulated in Air Mobility Command's (AMC) 2004 Air Mobility Master Plan, which states; "It [i.e., the MAF] is often called upon to deliver cargo and equipment to austere locations at any point on the globe (ref. para .1.3.4, MAF Capability Statements - Cargo Airlift)." These operations involve ". . . landing on semi-improved or austere airfields and can include forced-entry options and combat resupply of engaged troops." To provide this capability, US forces must be able to accurately determine the suitability of a proposed site. Today this determination relies almost exclusively upon a site survey team[4] visiting the location and assessing the proposed site or landing zone[5] (LZ). While a site survey provides an accurate assessment, it is a time consuming process and one that can compromise future operations if the presence of a site survey team is detected. The OLS will provide a means to assess the suitability of a given site through the use of hyper-spectral technology[6] without having to rely on a site survey team.

2. Background. Today, as it has been historically, only an on-scene site survey team can determine the suitability of a proposed LZ. Such was the case of the 1980 clandestine site survey of the Dasht-a-Kavir desert. Dasht-a-Kavir, the site of Desert One, was selected to serve as a C-

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[3] The focus of this document is on landing zone operations; however, the functionality of the OLS is also applicable to selecting drop zones and surface maneuver areas.

[4] Site Survey Team. For the purposes of this document a site survey team is a group of one or more individuals specially trained in determining the suitability of a location to support airland or air drop operations.

[5] Landing Zone. For the purposes of this document the term landing zone and assault zone can be used interchangeably. LZ operations are usually conducted on other than hard surface runways such as grass or clay. Normally, the dimensions for LZs s are more constrained than for normal runways; e.g., C-130 assault zones can be as small as 3000 feet long by 60 feet wide. In AMC, assault-landing operations require special aircrew training and qualification.

[6] Site selection should not be based solely on hyper-spectral technology if other data are available such as photo imagery, topographic data, environmental data, etc. . .

130 landing site to facilitate the refueling of US helicopters on the first night of Operation EAGLE CLAW (the attempted rescue of American hostages from Tehran, Iran). The site survey team arrived at the site, assessed its physical characteristics, determined soil strength, identified arrival and departure corridors, and oriented the LZ. Although the mission was successful, it highlighted several key aspects of the LZ selection process-- some of which are shortcomings OLS should alleviate and some are real world and/or operational constraints OLS must work within. Some of the constraints and shortcomings are discussed below:

- LZ Site Survey Real-World and/or Operational Constraints:
  - -- LZ Location. Operational requirements are the primary consideration in determining LZ location. Such was the case in Operation EAGLE CLAW, the helicopters could not perform their mission un-refueled and the region surrounding Desert One was the logical location for a fuel stop.
  - -- Operational Security. Force protection is a key consideration in any mission as it was in Operation EAGLE CLAW. The rescue of American hostages was a very close hold mission and the site selection process could not compromise the overall mission.

- LZ Site Survey Shortcomings:
  - -- Outdated Planning Data. The ability to identify possible LZ sites is dependent upon the currency and accuracy of the data used in the initial selection process. Depending on the area of operations, the available data may be very limited as was the case in the month prior to the Dasht-a-Kavir mission. Analysts were forced to use outdated topographic and environmental data to develop a list of candidate LZs because current data did not exist.
  - -- Manual LZ Prioritization. Once a proposed list of candidate LZs is developed, analysts must manually rank order them in terms of suitability due to a lack of automated tools.
  - -- Manual Determination of Soil Strength. The only current means available to determine soil strength is to conduct on-site soil strength testing. As a result, there is no analytical way to factor in soil strength in the initial rankings of LZ candidates.
  - -- Manual Identification of Aircraft Arrival and Departure Corridors. The most effective means available to determine arrival and departure corridors today, as was the case at Desert One, is to conduct a detailed analysis of topographic data and verify it with an on-scene appraisal. This method is extremely time consuming and dependent upon the quality of the topographic data available.

-- Manual LZ Orientation. The most effective means available to determine LZ orientation is to conduct a detailed analysis of topographic data and verify it with an on-scene appraisal. This method is extremely time consuming and dependent upon the quality of the topographic data available.

3. <u>OLS System Description</u>. The OLS will enhance the site selection process by reducing the overall site selection process to hours as opposed to days. Initially, the OLS should achieve this reduction through the use of up-to-date multi- and/or hyper-spectral imagery. Future enhancements should also include the use of photo imagery, topographical, and environmental data to determine soil properties and topographic features. Because the OLS mitigates the role of the site survey team it will enhance both operational and personnel security. The OLS consists of a man-portable image processing system and the necessary algorithms to process the data used to identify candidate LZs based on soil characteristics (e.g., gradients, obstructions, holes, vegetation, soil moisture content and load-bearing capacity). The image-processing unit will include a graphical user interface to allow the operator to select and modify variables (geographical coordinates, modes of operation, landing zone characteristics, etc. . .). The result will be a portable system that can identify LZs without relying upon an on-scene evaluation.

4. <u>OLS Demonstration Objective.</u> The objective of this demonstration is to prove the OLS can accurately determine the suitability of an LZ for mobility aircraft operations without requiring personnel to physically conduct a site survey. The primary basis for making this assessment will be multi- and/or hyper-spectral satellite data; however, other forms of data may be used to refine the assessment. As a goal, the OLS should be able to perform the following functions: (1) compile the necessary data, (2) process and analyze the data without user manipulation of the data, (3) provide an assessment of the suitability of an LZ (without user intervention), or (4) identify multiple LZs within a given area (without user intervention). The OLS assessment should take into account the following factors: surface conditions (size of surface particles, obstructions, undulations), LZ slope, slope of surrounding terrain, obstacle clearance within the "airfield environment" as well as along the departure and arrival corridors, and environmental factors (e.g., precipitation, wind, forecast weather conditions). As OLS matures it must also take into consideration aircraft weight, aircraft landing gear configuration, and numbers of landing/ takeoff cycles. In its final configuration the OLS should be able to provide an assessment as good as or better than one provided by a site survey team.

5. OLS Demonstration Concept of Operations. The OLS demonstration should not replicate earlier efforts by the Air Force Research Laboratory (AFRL) and industry; rather, it should build upon experience gained in earlier studies and incorporate lessons learned from those efforts. AFRL will determine the best methodology to demonstrate the OLS; however, one possible approach would be to conduct several phases using use a 'building block' approach. For example:

a. Phase I. Initially, the OLS would be used to determine the soil properties for a known LZ (or site) such as Sicily LZ, Ft. Bragg, NC. The OLS will process and analyze data. The results of that analysis will be compared to data collected manually for the same site during the same time period using current site survey procedures. This comparison should be conducted for several known LZs (or sites) with differing soil conditions over a period of time that includes seasonal changes. The results of this initial phase could be reported in terms of a confidence factor; i.e., the degree of confidence that the OLS computer generated analysis will correlate with the site survey team results.

b. Phase II. Once the demonstration team is satisfied with the confidence factor demonstrated in Phase I, the OLS could demonstrate its ability to select an appropriate site for an LZ(s) from a larger geographic region. As OLS matures it should be able to incorporate aircraft type (which OLS will use to define LZ size, as well as the approach and departure corridors to include obstacle clearance) and aircraft weight (which OLS will use to define required soil strength) to refine the identification of all possible LZs within a given geographic region. The OLS results will be analyzed for correctness and accuracy (where possible actual site survey results should be used). A confidence factor will be determined for the Phase II efforts.

c. Phase III. Phase III is similar to Phase II should be demonstrated as OLS matures. In addition to tasking the OLS to identify suitable LZs from a given geographic region, the OLS will be provided with the number of cycles (takeoffs and landings) the LZ must support both in terms of total cycles and in cycles/day for a set period of time. The OLS will select an appropriate LZ based on this cyclical loading; the results will be analyzed for correctness and accuracy (where possible actual site survey results will be used). A confidence factor will be determined for the Phase III efforts.

d. Phase IV. Phase IV will be a compilation of the previous phases. The OLS will select an LZ(s) and a site survey will be conducted on the proposed LZ(s) and the correlation between the OLS solution and the actual site survey team data will be determined.

6. OLS Procedures. The OLS demonstration should attempt to replace the work being done by the site survey team and delete the necessity for having to put 'boots-on-the-ground' to make an LZ selection. At this time, it is unknown whether AMC will delete the requirement to use site survey teams in the LZ selection process. However, it is assumed the OLS will reduce the tasks required of a site survey team.

7. Definitions. The following terms, used throughout this document, have definite meanings: “Shall,” “will,” or “must” mean the requirement/attribute is mandatory. “Should” or "could" mean the requirement/attribute is recommended.

8. Threats. There are no known specific threats targeted against the OLS; however, there are two existing threat scenarios the OLS can significantly mitigate. The first being the threat to personnel conducting a site survey. The second is the threat to operational success resulting from the compromise of an LZ location. The OLS will operate under a wide range of threat environments to include proximity to large number of emitters and electronic collection assets (both friendly and unfriendly) as well as operating in proximity of both friendly and enemy forces. Threat environments could impact the OLS in the following ways; disrupting its data collection capabilities, disrupting its data processing capabilities, compromising the integrity of its data processing capabilities, or by direct damage to the OLS equipment.

9. Possible Improvements to the Existing LZ Site Selection Process. The existing LZ site selection process has numerous areas for improvement. First, is the cycle time required to conduct a site survey once the need is identified. Once tasked, a site survey team must be assembled, transported to the proposed LZ site, the data collected, analyzed, and the results reported. Second, the use of personnel to conduct site surveys has inherent risks. The mere fact that an area is being surveyed could easily forewarn adversaries of forth-coming operations and place both the survey team and/or mission at risk depending upon the location of the proposed LZ.

10. Capabilities Required. The OLS must provide users the same level of fidelity, accuracy, and capability[7] as manned site survey teams can provide. The OLS must be compatible with and use the current geospatial datum reference, WGS 84, as well as the current AMC method of expressing soil-bearing capacity (e.g., California Bearing Ratio). OLS products must be in a format (electronic) that operators can manipulate, store, receive, or transmit securely. No current capability exists today to replace the LZ site survey team.

11. Key Operational Tasks. Since mission planning is more often a continuous process rather than one easily defined by specific stages, the key operational tasks identified below could occur at any stage in the planning cycle.

a. LZ validation. OLS will be tasked with validating an LZ selection. The operator will select a specific LZ based on operational necessity. The OLS will be given the definition[8] of the LZ and the date and time of the LZ's projected use. The growth path for the OLS needs to include the following parameters: aircraft type[9] and weight of the aircraft using the LZ as well as the projected cyclical use of the LZ.

b. LZ selection. OLS will be tasked with selecting LZ candidates from a user-identified region. The operator will select an area of operations based on operational necessity. The OLS will be given the definition[10] of the LZ and the date and time of the LZ's projected use. The growth path for the OLS needs to include the following parameters: the type[11] and weight of the aircraft using the LZ as well as the projected cyclical use of the LZ.

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[7] In terms of LZ site selection; i.e., suitability of the landing surface and sub-surface to support the required operations in addition to selecting adequate and appropriate arrival and departure corridors.
[8] Geospatial reference of the LZ in terms of latitude and longitude. Latitude and longitude references will be provided in sufficient detail to define the limits of the LZ, the limits of the airfield environment, and the arrival and departure and arrival corridors.
[9] By knowing the aircraft type the OLS should be able to determine the required obstacle clearance criteria for the specific aircraft both for ground operations within the airfield environment and the arrival and departure corridors.
[10] Geospatial reference of the region of operations in terms of latitude and longitude. Latitude and longitude references will be provided in sufficient detail to define the limits of the region.
[11] By knowing the aircraft type the OLS should be able to determine the required obstacle clearance criteria for the specific aircraft both for ground operations within the airfield environment and the arrival and departure corridors.

c. Generate LZ surveys. The OLS will be capable of generating a 'standard[12]' AMC LZ survey package to include any unique information flight crews or planners may require for safe, effective, and efficient mission execution. In the future, the LZ survey must be capable of being data linked to a MAF aircraft using AMC standard data link(s).

d. LZ re-validation/verification.. The system must store the user-entered parameters (e.g., aircraft type, aircraft weight, landing cycles, etc. . .) for recall and use at a later date. If re-validation/verification of an LZ is required, the OLS should only require the user to enter any updates to the previously entered data and perform the necessary calculations using the updated and previously entered data. If multiple LZs are being considered, the OLS must retain the data for each candidate LZ until the user deletes that particular data from the system.

e. OLS cycle time. The user should be presented the option of having the OLS use the most recent historical data for site selection or waiting for new data to be collected. That is, if the user needs an 'immediate' solution and historical data are acceptable, the OLS should perform its calculations without having to wait until new data are collected. The user must be able to easily determine which data was used by the OLS; i.e., type[13] and currency.

f. Drop zone (DZ) and surface area of operation selection. The selection of a DZ and/or surface area of operations has many of the same selection criteria as does an LZ (soil strength, surface slope, obstacle clearance. etc. . .). The use of the OLS in the role of selecting DZs and surface areas of maneuver is desired for this demonstration.

12. Key Performance Parameters (KPP). Since the OLS is a technology demonstration and is replacing an existing capability the following is the OLS KPP: The OLS must provide the same accuracy[14], repeatability[12], and fidelity[12] as the current site survey team process. Although not a KPP, the following desired capability should be evaluated if possible: Can the OLS detect sabotage of a previously selected landing zone; e.g., can the system detect subsurface irregularities such as pits or trenches covered with camouflage?

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[12] AMC standard LZ survey consists of the following: [AF Form 3822, IAW AFI 13-217; details to be inserted at a later date].
[13] Hyper-spectral technology, photo imagery, topographic data, and/or environmental data
[14] KPP Threshold

Appendix D: OLS Demonstration Requirements

Rqmt #	Requirement Name	Units of Meas.	Objec-tive	Thres-hold(s)	Requirement Description	Assumption, How Demonstrated or Other Clarification	Objective Rationale	Threshold Rationale	Customer Comments	Priority
Performance										
P01	Capability to ID Landing Sites	% of Suitable LZs Correctly Identified	100	50	Probability of designating a suitable landing zone (LZ) in a geographical region, given that a suitable LZ exists in the region—a measure of accuracy without consideration of bearing strength.	Percentage of Correct LZ IDs [Pr(CrIDs)]. Pr CrIDs = (Area in Correct LZ ID'd) ÷ (Total Area of LZs in region analyzed). Comparison of software analysis results with inspection and observation results for St. Clair County, IL (Task 1)	Ideally, the OLS would correctly identify all areas suitable for LZs in a region under study.	The OLS shall demo the capability to correctly designate the existence and location of landing sites at least 50% of the time.	Exit criterion and KPP.	High
P02	Capability to Determine Bearing Strength of ID'd LZs	Predicted/Actual CBR	1	1.05	FASST-predicted CBR ÷ Actual LZ CBR. Predictions made at 85% confidence level.	Validation of OLS predictions through field sampling and comparison of software predictions with DCP-measured CBRs. (Task 2)	Until there is very high confidence in the OLS soil-strength predictions, it is unlikely that aircraft will be authorized to land without a site survey.	Overestimate of bearing strength is a serious problem; underestimation is less serious, though it may preclude finding suitable LZs. Must have 85% confidence that the actual CBR is greater than or equal to that provided by the system.	Exit criterion and KPP.	High
P03	Low Incidence of False Positives	Pr(Incor-rect ID)	0	N/A	Probability of designating an unsuitable landing site as a suitable LZ--a measure of accuracy.	Comparison of software analysis results with inspection and observation results for St. Clair County, IL (Task 1)	Ideally, there would be no false positives.	The OLS software should not incorrectly report suitable sites; however, no threshod must be met for the demo.	Neither an exit criterion nor a KPP for the demonstra tion.	High
P04	Repeatability	Pr(Same Answer)	100	90	Percentage of time OLS returns the same results using the same entry parameters (given area at a particular time).	Software validation based on acceptance testing. (Task 3)	Given the same entry parameters for the same area at the same time, the system provides the same answers.	Demo the capability (may report results of lab testing used to reach demo threshold, but should demo at least one example of repeatability).	Exit criterion and KPP.	High

Rqmt #	Requirement Name	Units of Meas.	Objec-tive	Thres-hold(s)	Requirement Description	Assumption, How Demonstrated or Other Clarification	Objective Rationale	Threshold Rationale	Customer Comments	Priority
	Performance									
P07	Flexibility and Longevity	Scale: 1 to 6	6	2	Ability of OLS to function even if Landsat or other asset relied upon as a data source is no longer available.	Scale: 6 = very satisfactory; 5 = satisfactory; 4 = marginally satisfactory; 3 = marginally unsatisfactory; 2 = unsatisfactory; 1 = very unsatisfactory Assessment by AMC-designated evaluator based on information provided by Boeing. (Task 4)	A capability is desired, regardless of available data source.	Address impact to OLS performance if one or more sensors are no longer available (e.g., LANDSAT satellite is decommissioned).	Aster, Digital Globe, Advanced Visible IR Imaging Spectrometer (AVIRIS) (airborne sensor) are other data sources available in the near-term. Need to address this in the transition plan. Need to anticipate the difficulty of keeping OLS viable as the original sensors are replaced or become obsolete.	Low
P09	Capability to Operate in All Weather	Scale: 1 to 6	6	2	Ability of OLS to function in all weather conditions, regardless of cloud cover or precipitation, obscuration by terrain, etc.	6-Point Satisfaction Scale; see P07 for definition. Assessment by AMC-designated evaluator based on information provided by Boeing. (Task 4)	Demo the capability, if possible; if not, address weather/atmospheric limitations.	Currently not feasible because of sensor limitations. Need to know how weather and atmospheric conditions will affect OLS performance. Can be handled by report for demonstration.	Not an exit criterion. Must be reflected in Tech Mat Plan to OLS end state.	High

Rqmt #	Requirement Name	Units of Meas.	Objec-tive	Thres-hold(s)	Requirement Description	Assumption, How Demonstrated or Other Clarification	Objective Rationale	Threshold Rationale	Customer Comments	Priority
	Performance									
P11	Ability to Accept User-Defined Parameters	Scale: 1 to 6	6	4	Ability of OLS to process inputs provided by users, including parameters like length, width, ratio requirement, CBR, glideslope, MOG, etc.	6-Point Satisfaction Scale; see P07 for definition. Assessment by AMC-designated evaluator based on information provided by Boeing. (Task 5)	Ability to change parameters based on operations, changes in mission in flight, etc. that might require changed input parameters is desired.	The mission should dictate the parameters for the OLS search. Operators need this flexibility. Assume no GUI in place for demo; operator specifies parameters, which are entered by s/w driver.	Exit criterion; not a KPP.	Med
P12	Flexibility in Finding More than LZs	Scale: 1 to 5	2	1	Ability of OLS to perform other functions; e.g., assessing overland mobility, finding areas for base camps and drop zones (DZs), etc., so long as the criteria are similar to those for LZs.	Rank based on what it can find and the difficulty of finding it. Scale definition based on ability to find the following: 5=4+routes/comm lines; 4=3+marshalling areas; 3=2+base camps; 2=1+drop zones; 1=LZs onlyAssessment by AMC-designated evaluator based on information provided by Boeing. (Task 5)	Would like to find LZs and drop zones.	At a minimum, must find LZs. The capability for OLS to find more than LZs (marshalling areas, lines of communication, etc.) should be addressed.	Not an exit criterion or a KPP.	Low

Glossary

AFB	Air Force Base
AFCESA	Air Force Civil Engineering Support Agency
AFR	Air Force Regulation
AFRL	Air Force Research Laboratory
AFSOC	Air Force Special Operations Command
AJACS	Advanced Joint Air Combat System
AMC	Air Mobility Command
AMC-X	Multi-Mission Mobility Aircraft System
ATD	Advanced Technology Demonstration
ATT	Advanced Theater Transport
BLSI	Boeing Landing Suitability Index
CBR	California Bearing Ratio
CONUS	Continental United States
CRREL	Cold Regions Research and Engineering Laboratory
DTED	Digital Terrain Elevation Data
ENVI	Environment for Visualizing Images
ERDC	Engineer Research and Development Center
FASST	Fast All-Season Soil Strength
FOC	Full Operational Capability
GIS	Geographic Information System
GUI	Graphic User Interface
IDL	Interface Definition Language
IRAD	Internal Research and Development
KPP	Key Performance Parameter
LZ	Landing Zone
MAF	Mobility Air Forces
MM5	Mesoscale Model 5
NAR	Non-Advocate Review
OLS	Opportune Landing Site(s)
OLS-EVM	Opportune Landing Site – Extended Vector Method
OLS-MS	Opportune Landing Site – MultiSpectral

OUSD/AT&L	Office of the Under Secretary of Defense for Acquisition, Technology & Logistics
PDD	Potential Drainage Density
POM	Program Objective Memorandum
RAS	Runway Assessment Site
SETFST	Systems Engineering Tailored For Science & Technology
SRTM	Shuttle Radar Topography Mission
SSTOL	Super-Short Takeoff and Landing
STT	Special Tactics Team
TACC	Tanker Airlift Control Center
TM	Thematic Mapper
TM+	Thematic Mapper Plus
TRADOC	Training and Doctrine Command
TTI	Technology Transformation Initiative
USAFE	United States Air Forces in Europe
USCS	Unified Soil Classification System
USTRANSCCOM	United States Transportation Command
WGS	World Geodetic System
WRF	Weather Research and Forecasting